GEOLOGICAL

GUIDE-BOOK

FOR AN EXCURSION TO THE

ROCKY MOUNTAINS.

SAMUEL FRANKLIN EMMONS,
EDITOR.

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CONGRESS OF GEOLOGISTS.*]

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OF THE

ROCKY MOUNTAIN EXCURSION

EDITED BY

SAMUEL FRANKLIN EMMONS

INTRODUCTION.

EXCURSION TO THE ROCKY MOUNTAINS.

The undersigned was called upon, a few weeks before the opening of the Congress, to prepare a geological guide book for the use of those members of the Congress who should take part in the proposed excursion to the Rocky Mountains.

Parts of the vast region to be passed over during the excursion had never been systematically examined; of other parts the results of recent examinations had not yet been published, and the published surveys of still other parts were scattered through many bulky Government, State, and other reports, all of which it would have been impossible to consult in the time given, and many of which had been more or less superseded by later and as yet unpublished observations. Under these circumstances the only feasible plan for preparing such a guide book was to call upon geologists within reach, who were most familiar with different parts of these regions, to contribute descriptions of the geology of such parts. Those thus called upon responded most promptly and generously, but their contributions necessarily varied somewhat in detail and method of treatment, according to the varying conceptions of the authors. It was not possible, in the limited time given, to return their manuscripts to the authors for revision so as to produce the necessary uniformity, and the duty therefore fell upon the editor of hastily rewriting a considerable portion of the material contributed, and of filling in any gaps to the best of his personal knowledge. The resulting guide book was necessarily somewhat unequal in the amount of detailed description given of different parts of the region, and also incomplete in illustration and bibliographic reference. In spite of these imperfections, it so well subserved its purpose that a unanimous request was made by the other secretaries, who had taken part in the excursion, that it should be published in the Compte-rendu, after revision by the various contributors of the parts for which they were to be held responsible, and the addition of as many illustrations and bibliographic references as possible. This request has been complied with, as far as has proved practicable, in the following pages. In a few cases the original contributors have been too busy to revise their notes, and the editor has been obliged to present the description of their regions much as they originally appeared. In other cases, where the descriptions contained in the original guide


WESTERN EXCURSION
OF THE
INTERNATIONAL CONGRESS OF GEOLOGISTS
September, 1891.
(Base map prepared by Eleventh U.S. Census)
Main Route
Branch Routes
GREAT BASIN
THE ROCKY MTS
PLATEAU REGION
GREAT PLAINS
PRAIRIES
APPALACHIAN MTS
Livingston
Cinnabar
Shoshone Falls
Pocatello
Glenwood
Manitou
Canyon City
Grand Canyon
Flagstaff
Albuquerque
Niagara Falls
GULF OF MEXICO
Scale
Miles
Kilometres
ENGRAVED BY U.S.G.S.

book were a compilation of the notes of several individuals, it has been difficult to divide the parts so as not to interfere with the continuity of the description. Whatever has been lost in this respect, however, has been more than made up by the greater fullness of treatment. The lists, prepared by each contributor, of publications containing the most recent and important geological information in regard to the respective areas described have, for convenience of reference, been combined into a single list placed at the end of the sketch, references being made by means of numbers in the text corresponding to the numbers affixed to each title.

Some of the visiting geologists have kindly contributed notes and sketches made by them during the journey, which form a valuable addition, and it is only to be regretted that they are not more numerous.

S. F. EMMONS,
Editor.

LIST OF ILLUSTRATIONS.

List of Railroad Lines followed by the Excursion.

Day.	Main Route.	Distance Miles.	Distance Kilometers.
	Baltimore and Ohio R. R.:		
First	*Metropolitan Branch*—Washington to Washington Junction.	43	69
	Main Line—Washington Junction to Wheeling, W. Va.	310	499
	Central Ohio Division—Wheeling, W. Va., to Newark, Ohio	101	162
Second	*Lake Erie Division*—Newark to Chicago Junction, Ohio	88	142
	Chicago Division—to Chicago, Ill	271	436
	Chicago, Milwaukee and St. Paul R. R.:		
	Chicago Division—Chicago to Milwaukee, Wis	85	137
	La Crosse Division—Milwaukee to La Crosse, Wis	198	318
Third	*River Division*—La Crosse to St. Paul, Minn	127	204
	River Division—St. Paul to Minneapolis, Minn	10	16
	Northern Pacific R. R.:		
Fourth	*St. Paul, Minneapolis and Pacific Coast Line*—Minneapolis, Minn., to Livingston, Mont	996	1,603
Fifth	*Yellowstone Park Branch*—Livingston to Cinnabar	51	82
Twelfth	*Yellowstone Park Branch*—Cinnabar to Livingston	51	82
	Pacific Coast Line—Livingston to Logan, Mont	49	79
	Butte Branch—Logan to Butte, Mont	71	114
	Union Pacific R. R.:		
	Utah Northern Line—Butte, Mont., to Pocatello, Idaho	263	423
Thirteenth	*Utah Northern Line*—Pocatello to Ogden, Utah	134	216
	Rio Grande Western Railway:		
	Ogden to Salt Lake City	36	58
Sixteenth	Salt Lake City to Grand Junction, Colo	292	470
	Denver and Rio Grande R. R.:		
Seventeenth	*Denver and Salt Lake Line*—Grand Junction to Leadville	169	272
Eighteenth	*Denver and Salt Lake Line*—Leadville to Colorado Springs	202	325
	Manitou Branch—Colorado Springs to Manitou	5	8
Nineteenth	*Manitou Branch*—Manitou to Colorado Springs	5	8
	Denver and Salt Lake Line—Colorado Springs to Denver	75	121
	Union Pacific R. R.:		
Twentieth	*Kansas Division*—Denver to Limon, Colo	90	145
	Chicago, Rock Island and Pacific Railway:		
Twenty-first	*Kansas City and Colorado Line*—Limon, Colo., to Topeka, Kans	476	766
	Union Pacific R. R.:		
	Kansas Division—Topeka, Kans., to Kansas City, Mo	67	108
	Hannibal and St. Joseph R. R.:		
	Kansas City to Cameron Junction, Mo	54	87
	Chicago, Rock Island and Pacific Railway:		
Twenty-second	*Southwestern Division*—Cameron Junction, Mo., to Chicago, Ills	464	746
	Chicago and Grand Trunk Railway:		
Twenty-third	Chicago, Ills., to Port Huron, Mich	335	539
	Grand Trunk R. R.:		
Twenty-fourth	*Southern Division*—Sarnia, Ontario, to Suspension Bridge, N. Y	184	296
	New York Central and Hudson River R. R.:		
	Suspension Bridge to Niagara Falls	2	3
	Niagara Falls to Buffalo	22	35

List of Railroad Lines followed by the Excursion—Continued.

Day.	Main route.	Distance. Miles.	Distance. Kilometers.
	West Shore R. R.:		
Twenty-fifth	Buffalo, N. Y., to Weehawken, N. J	428	689
	BRANCH ROUTE TO SHOSHONE, IDAHO.		
	Union Pacific R. R.:		
	Oregon Short Line—Pocatello, Idaho, to Shoshone, Idaho...	106	171
	BRANCH ROUTE TO FLAGSTAFF, ARIZ.		
	Atchison, Topeka and Santa Fé R. R.:		
	Denver, Colo., to Albuquerque, N. Mex....................	529	871
	Atlantic and Pacific Division—Albuquerque to Flagstaff, Ariz...	344	554
		6,733	10,854

N. B.—Figures above the line in the text refer to titles in Bibliographic list, p. 482, et seq.

EXCURSION TO THE ROCKY MOUNTAINS.

PHYSICAL GEOGRAPHY OF THE REGION.

By G. K. Gilbert.

In journeying three-fourths of the distance from the Atlantic to the Pacific, the excursion crosses a number of distinct topographic provinces, as well as districts characterized by a wide range of climatic conditions. By way of introduction to the details described in subsequent chapters, a few paragraphs will be devoted to the characterization of the general physiographic and climatic types of the country to be traversed.

The most general classification of the United States into physiographic provinces indicates an Appalachian region at the east, a Cordilleran region at the west, and a broad plain between drained by the Mississippi and the St. Lawrence rivers. In the Appalachian region six belts are distinguished—the Coastal plain, the Piedmont plain, the Blue ridge, the Appalachian valley, the Appalachian mountains, the Cumberland plateau. They all trend approximately northeast and southwest, and, as is the case with other physiographic provinces, they are clearly differentiated in some districts and difficult of discrimination in others. We are concerned chiefly with their aspects on the line of journey.

Washington City stands at the boundary between the Coastal plain and the Piedmont belt. If any river on the Atlantic coast, from New Jersey to the Carolinas, be followed from its mouth, a cataract is sooner or later reached and navigation interrupted. A line across the land connecting these cataracts is known as the "fall line," and gives the northwestern limit of the Coastal plain. The Coastal plain is characterized by level strata, little indurated, having essentially the attitude of deposition. These strata are Cretaceous and newer. The general elevation is not great, and the northern portion of the plain is interrupted by great tidewater bays, due to the sinking of the land and the drowning of the river valleys.

The Piedmont belt is in general a plain somewhat higher than the Coastal plain, and bearing small hills or even small mountains. Its surface is generally undulating, and the greater lines of drainage are abruptly incised. The plain is carved from indurated and folded rocks of various ages, partly Jura-Trias, but chiefly metamorphic. On the outward journey the belt is crossed between Washington and

Weverton, and on the return it is theoretically crossed between the Highlands of the Hudson river and New York City, but its manifestation there is not characteristic.

The Blue ridge overlooks the Piedmont district from the northwest, and is a nearly continuous upland from New England to Georgia. At most points it is a single ridge rising 2,000 feet above adjacent lowlands, but in North Carolina it is expanded into a mountain chain, with greater altitude. The outward journey intersects it in approaching Harpers Ferry; the return journey, at the Highlands of the Hudson.

The Appalachian valley is a wonderfully persistent belt of lowland separating the Blue ridge from the Appalachian mountains. For several geologic periods the Appalachian region has stood at so low a level that its streams have had small declivity, and mechanical erosion has been slow. The chemical factor in erosion has thus acquired relative prominence, and the broad outcrop of lower Paleozoic limestone which occupies the valley area has been degraded by solution until its surface is far below the contiguous outcrops of sandstone and shale. It is an undulating plain, sharply incised along principal lines of drainage, and otherwise characterized by "swallow holes" or "limestone sinks," and by caves. The outward journey traverses it from Harpers Ferry to North Mountain Station; on the line of the return journey it is not well distinguished.

The Appalachian mountains*[1] consist of Paleozoic strata, from Cambrian to Carboniferous, which have been acutely folded and faulted. The steeper limbs of the fold are usually on the northwest side. Anticlines are often pushed northwestward over synclines, and in numerous instances this process has culminated in thrust faults. The principal epoch of folding ended early in Mesozoic time, and during the latter part of the Mesozoic the district, which then stood several thousand feet lower than now, was degraded to the condition of a peneplain. Subsequent uplift renewed the activity of the streams, and the district was carved into a grand cameo, in which the topographic features express the rock texture and rock structure in a peculiarly effective manner. The outcrop of each series of soft rocks is recorded in a system of valleys; each great bed of hard rock caps a ridge, but none of the ridges rise above the level of the old peneplain, and all the greater ridges have even tops expressing that factor of their history. On the outward journey this belt is traversed from North Mountain to the Monongahela river; on the return journey it is entered at Schenectady, but its features are masked by Pleistocene deposits.

The Appalachian folding diminishes in intensity northwestward until finally the dips of the strata are gentle. Wherever a massive sandstone approaches the height of the old peneplain in the region of gentler folds it has been preserved in the form of a high table, usually

* Figures above the line refer to titles in Bibliographic list at end of Guide Book.

with an abrupt escarpment toward the southeast. The Cumberland plateau is a belt of such tables. It is thus a connecting link between the Appalachian mountains and the interior plain, but it is not everywhere to be recognized. On the line of the outward journey it is not discriminated. On the line of the return journey it is represented by the Catskill mountains, which are visible in the distance from the west (right) side of the train as it follows the Hudson River.

The central plain of the continent does not yield a simple and definite classification into physiographic provinces, but the portion traversed by the excursion may be imperfectly characterized by describing three topographic types which it illustrates: the Lake region, the Prairie region, and the Great plains. The Lake region[2] is a rather uneven plain, having for its foundation, at the north, crystalline rocks of complex structure which are so degraded that all mountains are obliterated, and at the south, Paleozoic rocks, level or gently folded, and likewise degraded to approximate evenness. Over these are deposits of glacial drift, irregularly disposed so as to break the surface into a large number of basins, holding lakes, lakelets, ponds, and swamps.[3] On the outward journey this region is traversed in the States of Ohio, Indiana, Illinois, Wisconsin, Minnesota, and a part of North Dakota; on the return journey, in Illinois, Indiana, Michigan, Canada, and western New York.

The Prairie region is less susceptible of mapping than most other divisions, because it depends on complex conditions involving climate as well as surface configuration. Humid lands are normally characterized by forest and are suited for agriculture; arid lands are normally characterized by the absence of forest, and are unsuited for agriculture without irrigation. The normal distribution of forest is modified by fire, as annual fires destroy forests but permit the growth of grasses. In regions of great humidity a forest fire does not spread with facility; in regions of rugged surface it is limited by topographic accidents; in regions of moderate humidity and smooth surface a forest is destroyed by fire, and thus a fertile region becomes bare of trees and is clothed by grasses. The outward journey traverses prairie in western Minnesota and adjacent North Dakota. A typical portion of the prairie belt is traversed on the return journey in Missouri, Iowa, and Illinois.

The Great plains slope eastward from the eastern foot of the Rocky mountains, descending from altitudes of 5,000, 6,000, and 7,000 feet (1,500, 1,800, 2,100 m.) nearly to sea level. In detail the surface undulates gently and is devoid of commanding eminences, except that the Ozark uplift has produced low mountains in Texas, Arkansas, Indian Territory, and Missouri; the Black Hills uplift has produced another group at the western edge of South Dakota; and a few buttes, mostly

of volcanic origin, stand near the Canadian boundary. The underlying strata are chiefly Cretaceous and Tertiary, and in general these have been reduced to an even surface. In a few districts, however, local causes have accelerated corrasion, causing the sculpture of shaly beds into the picturesque "Bad lands." On the outward journey the Great plains are traversed in North Dakota and the eastern half of Montana; on the return journey, from Denver to the Missouri river. The branch route to the Colorado canyon traverses the western edge of the plains from Denver to Las Vegas.

The Cordilleran region includes the Rocky mountains, the Plateau region, the Great basin, the Snake River plain, the Sierra Nevada, and a number of more westerly divisions beyond the limits of the journey.

The name Rocky mountains is applied in Colorado and northern New Mexico to the complex mountain chain lying between the Great plains and the Plateau region, and in Montana and northern Wyoming to the mountain chain between the Great plains on the east and the Snake River plain on the west. In central Wyoming there is a discontinuity, the mountain chain being interrupted by an arm of the Plateau region known as the Laramie plain. The Rocky mountains of Colorado constitute the greatest mountain mass of the United States, although a few peaks in the Sierra Nevada exceed them in height. Their principal uplift took place at a later date than that of the Appalachian Mountains, and they are far more rugged. The type of structure involves less of closely compressed folding, and faulting has played a more prominent part in producing their present relief. The nucleal rocks range from crystalline schists through the Paleozoic. Mesozoic strata appear about the flanks, sharing in the uplift, and lacustrine beds of Cenozoic date rise against the bases on all sides and are to be discovered in most of the mountain valleys. In various places, and especially toward the south, there are great masses of volcanic rocks, and dikes abound in all parts. The Rocky mountains of the northern group are of similar type, and also consist of lofty and rugged ranges. From these two masses flow the longest rivers of the country. The Mississippi-Missouri rises in the northern chain, receives many affluents from the southern, and flows southward to the Gulf of Mexico. The length of its main line is 4,900 miles (7,080 km.). The Columbia, rising in the northern chain, reaches the Pacific Ocean after flowing 1,400 miles (2,200 km.). The southern chain likewise sends the Rio Grande 2,000 miles (3,200 km.) to the Gulf of Mexico, and is drained on the west by the tributaries of the Colorado, whose waters flow 1,300 miles (2,100 km.) to the Gulf of California. On the outward journey the route lies along the mountains of the northern chain from Cinnabar to Pocatello; on the return journey it lies among the Rocky mountains of Colorado,

from Grand Junction to Canyon city, and thence to Denver skirts the base of the Front range. The branch route to the Colorado canyon crosses the southern extension of the chain in New Mexico between Las Vegas and Albuquerque.

The Plateau region lies between the southern Rocky mountains on the east, and the Great basin on the west. Structurally, it consists of stratified rocks of all ages, in chief part conformable, and usually lying nearly level, but dislocated in great orogenic blocks which stand at different altitudes. With them are associated eruptive rocks, in part injected as laccolites, and in part heaped in conical mountains. Its physiographic character is further determined by the fact that the region stands at great altitude above the sea, and has been profoundly dissected by the streams constituting its drainage system. It thus consists of a number of tables, standing at various heights, and separated partly by cliffs and partly by deep canyons. The return route traverses the region from Soldiers Fork in Central Utah to Grand Junction in western Colorado. On the branch route to the Colorado canyon it is traversed from Albuquerque westward.

The Great basin is a district without drainage to the ocean. It is bounded on the west by the Sierra Nevada, and on the north, east, and south by the basins of the Columbia and Colorado. At the north its lowlands have a general elevation of 4,000 to 6,000 feet (1,200 to 1,800 m.), and they descend southward to the level of the sea. Upon this sloping plateau are set a multitude of mountain ranges, for the most part of moderate height and of moderate length.[4] They are in general parallel with one another, the prevailing trend at the north being north and south, and at the south, northwest and southeast. The intervening valleys are flooded by alluvium derived from the erosion of the ranges, and are usually 15 to 20 miles (24 to 32 km.) broad. The ranges are party volcanic, but consist chiefly of Paleozoic strata, sometimes with folds, but nearly always profoundly faulted. The typical structure is in contrast with that of the Appalachians. In the Appalachian mountains are thrust faults, indicating compression of the strata; in the Great basin the faults exhibit hade to the downthrow. The ridges of the Appalachian mountains, as exhibited to day, are due to differential erosion; the mountain ridges of the Great basin are due directly to uplift. The excursion enters the Great basin at Red Rock pass, in Idaho, and continues within it to the summit at the head of Soldiers fork, in eastern Utah.

The type of mountain structure of the Great basin, which has been called the "Basin Range type," is not restricted to the region of interior drainage, but prevails throughout a belt extending southward and eastward, about the margin of the plateau region, in Arizona and New Mexico.

CLIMATIC FEATURES.

The entire route falls within the climatic province of variable rains. In some localities there is ordinarily greater precipitation at some seasons than at others, but there is no district where at any season precipitation is regular or continuous. Rainfall and snowfall are associated with cyclonic or other disturbances of atmospheric equilibrium. The temperatures are those normal to the temperate zone; except on mountains and lofty plateaus, wheat and Indian corn are grown and the apple is the leading fruit.

The most conspicuous climatic contrasts are afforded by the local differences in the annual amount of precipitation and in the annual and diurnal range of temperature. The outward route from Washington to Minneapolis, and the return route from the Missouri river to New York traverse a region of essentially the same climatic type. The annual temperature mean ranges from 40° to 55° F. (4° to 13° C.), the precipitation ranges from 30 to 45 inches (90 to 135 cm.). The surface is normally timbered and deciduous trees prevail. Occasional patches of prairie interrupt the forest throughout, but they increase toward the west and finally predominate. The whole country is fertile without irrigation. The annual range of temperature (the difference between the coldest month and the warmest) is about 50° F. (27° C.). The length of the summer suffices for the growth of the leading food staples.

Westward to the base of the Rocky mountains the rainfall gradually diminishes to less than 15 inches (45 cm.); trees disappear except along the water courses, where the cottonwood (*Populus monilifera*) flourishes, and they are replaced by grasses. Farther westward the grasses become scant, and are partially replaced by an open growth of low bushes. Farming without irrigation becomes at first precarious and finally impossible, and grazing supersedes agriculture as the leading industry. At the same time the annual temperature range increases to about 60° F. (33° C.), and the diurnal range is likewise greater, as the excursionists will readily discover.

Throughout the more westerly portion of the route, in the Rocky mountains, the Great basin, and the Plateau region, the most important local climatic condition is altitude, and the native floras and faunas are arranged in belts which follow contours, but these contours run somewhat lower at the north than at the south. Precipitation varies with altitude, and temperature inversely with altitude. The plain of western Utah, with an altitude of 4,500 feet (1,375 m.), has an annual temperature of 75° F. (24° C.) and a rainfall of about 7 inches (21 cm.). Yellowstone Park, with an altitude of 6,500 feet (1,980 m.), has an annual temperature of 40° F. (4° C.) and a precipitation of 20 inches (60 cm.). At Leadville, 10,200 feet (3,100 m.) above the sea, the annual temperature is 35° F. (2° C.) and the precipitation 13 inches (40 cm.).

In western Utah the winter is 80° F. (44° C.) cooler than the summer; in Yellowstone Park, 50° F. (27° C.); at Leadville, 43° F. (24° C.).

The principal zones of vegetation are known as the desert, the pinon, the pine, the balsam fir, the spruce, and the subalpine.[5] In the desert zone there are no trees, except that the cottonwood occasionally follows the lines of streams. Bushes, of which the sage is the most important, have an open growth, usually offering no impediment to the progress of pedestrian or horseman. With these are grasses, invariably growing in discrete bunches so as not to constitute a turf. The prevailing color of earth, grass, and bushes is ashen. Near springs and perennial streams grow other grasses and bushes with more chlorophyl, so that bright green is to the desert wanderer the welcome sign of water.

The pinon zone is characterized by two species of evergreens, the nut pine (*Pinus edulis*) and the "cedar" (*Juniperus occidentalis monosperma*). The pine is ordinarily from 20 to 30 feet (6 to 9 m.) high, and the cedar from 15 to 25 feet (4 to 7 m.).

The pine zone is characterized by the yellow pine (*Pinus ponderosa*), a beautiful tree, 70 to 100 feet (20 to 30 m.) high, the groves of which stand in open order, without underbrush and without low branches. This tree is rarely associated with others, but waterways traversing its zone sometimes nourish a few individuals of various deciduous species, including the maple, the ash, and the box elder.

The characteristic tree of the balsam fir zone is the Douglas fir (*Pseudotsuga douglasii*). With it are associated the Rocky Mountain pine (*Pinus flexilis macrocarpa*) and the aspen (*Populus tremuloides*). The Douglas fir is a commanding tree, the rival of the yellow pine.

The spruce zone is characterized by the Engelmann's spruce (*Picea engelmanni*) and the foxtail pine (*Pinus aristata*). The spruce, which ordinarily predominates, is a beautiful tapering cone, its lower branches resting upon the ground.

In the subalpine zone Engelmann's spruce and the foxtail pine become gnarled and procumbent.

In the western region the precipitation of the winter is ordinarily greater than that of the summer, and on the mountains and uplands it takes the form of snow. In the spring and early summer this snow is melted and streams are nourished which flow to the lowlands, where the temperature is favorable to agriculture. Thus, despite the aridity of the lowlands, man is enabled to cultivate a limited portion of the land. The land thus cultivated yields a much greater return than can be obtained in the humid districts farther east. The great power of solar rays transmitted through a clear atmosphere of low humidity, combined with the rapid evaporation of moisture from the leaves of plants, gives a wonderful stimulus to vegetation, and, where the water for irrigation is abundant and skilfully applied, the yield is large.

THE APPALACHIAN REGION.*

By G. H. Williams.

The first day's ride of the excursion is well calculated to give a clear idea of the character of that regular mountain belt which bounds the entire North American continent on its southeast side. The general type of Appalachian structure is well known to all geologists, either through the classic work of the brothers Rogers,[1] or from the summary of their results given by Dana and others. The railroad course to be followed during the first day traverses the entire belt from east to west along one of its narrowest, deepest, and most characteristic sections, i. e., that which has been excavated by the Potomac River.

The recent work of several geologists, but notably that of Mr. W J McGee,[6] has clearly demonstrated the divisibility of the mountain and coastal portion of the eastern United States south of New York into three topographically and geologically distinct provinces or zones. Together they embrace nearly the entire sequence of geological formations, while at the same time the age, petrographical character, and structure of each is widely different from that of the others.

The most recent, as well as the most easterly, of these three zones is called the Coastal plain. It varies greatly in width between New York and Florida, but is throughout composed of nearly unconsolidated Mesozoic and Tertiary strata (clays, sands, and gravels), which dip very gently seaward, and in this direction grow steadily younger. Over all, however, is spread a capping of Pleistocene gravel (Columbia). The western edge of this Coastal plain may be regarded as approximately coincident with a line drawn from New York to Washington, and it is not improbable that a flexure or fault, still in process of development along this line, separates it from the crystalline region on the west.[7]

The next of the three provinces or zones in point of geological age, although not the one geographically contiguous to the Coastal plain, is the Appalachian Mountain belt. These two are separated by the third, and much the most ancient zone, composed of highly crystalline rocks, or semicrystalline rocks, and known as the Piedmont plateau.

The Appalachian Mountain Belt embraces nearly the entire sequence of Paleozoic strata. In the section to be traversed during daylight,

*A more extended account of the Maryland section through the Appalachians accompanied by a geological map of the strata in colors, has been published in the World's Fair book "Maryland," 1893, and reissued by the Joh Hopkins University Press as "The Geology and Physical Features of Maryland."

however, no beds lower than the Chazy-Trenton horizon have as yet been certainly identified upon paleontological evidence, while at the top of the series the Permian strata are wanting. Between these limits the series is quite complete, although many of the members are, in comparison with their Pennsylvanian equivalents, considerably attenuated. The formations distinguishable along the Potomac section are for the most part the same as those recognized by the Pennsylvania geological survey. The names and numerals by which these are usually designated are given, for convenience of reference, in the following table:

	No.	New York and Pennsylvania names.	Maryland and Virginia equivalents.
Carboniferous.	XV	Productive Coal Measures	Pittsburg series.
	XIV		Barren Coal Measures.
	XIII		Alleghany River series.
	XII	Pottsville conglomerate (Millstone grit).	Great conglomerate.
	XI	Mauch Chunk red shales; Mountain limestone	Greenbrier shales.
	X	Pocono sandstone (Vespertine)	Montgomery grits.
Devonian.	IX	Catskill sandstone	Hampshire.
	VIII	Chemung; Hamilton (Marcellus) shales	Jennings-Romney.
	VII	Oriskany sandstone	Monterey.
Silurian.	VI	Lower Helderberg limestone; Salina group (sandstone)	Cement rock.
	V	Niagara limestone. Clinton shales	Rockwood.
	IV	Medina sandstone; Oneida conglomerate	Massanutten sandstone.
Siluro-Cambrian.	III	Hudson River shales	Martinsburg shale.
	II	Trenton-Chazy limestone	Shenandoah limestone. "Valley limestone."
	I	Potsdam sandstone	

This thick succession of conglomerates, sandstones, shales, and limestones accumulated as a part of the deposits of the vast sea which, during Paleozoic times, occupied the interior of the North American continent. Since these formations are so much thicker in the Appalachian belt than in the Mississippi basin they must, as has been shown by Hall[8] and Dana,[9] have been deposited in a trough which was undergoing a gradual depression. Their aggregate thickness in Pennsylvania is estimated at 40,000 feet. There is every evidence that this vast deposition took place from the east toward the west, and we are obliged to assume as the source of supply for so great an amount of material, a continental mass over and beyond what is now the Coastal plain. It is not improbable that the more crystalline portion of the Piedmont plateau may represent a remainder of this eroded and sunken continent. The conditions of accumulations through Paleozoic times were probably quite similar to what they have been and still are

for the Coastal plain, if we imagine the direction of the drainage and position of the sea to be reversed, i. e., on the west instead of on the east.

At or near the end of the Carboniferous period, when the accumulations of sediments must have transformed the deep Appalachian trough into shallow marshes or estuaries, the vast thickness of strata were folded into the remarkably regular series of wrinkles which give to this mountain range at present its peculiar character. A cross-section of the Appalachians is nowhere symmetrical. On the contrary, it presents only one side or half of a symmetrical range, for it is composed of anticlinal and synclinal folds, all more or less overturned toward the west and also becoming steadily more and more abrupt toward the east. Along the section cut through the Appalachians by the Potomac River for instance, which the line of the railway follows very closely, one finds on the west side, between Cumberland and Grafton (in Garrett County, Md., and in West Virginia), only the low, flat folds of upper Paleozoic strata inclosing the nearly horizontal coal beds. Further east these gently sloping basins are replaced by others whose sides are steeper and which also display older rocks. It is then observed that each anticlinal has its western side more steeply inclined than its eastern, and still farther east both sides may dip toward the ocean so as to make the fold overturned. Last of all, the fold may become too sharp for the strength of the materials to stand, when the flexure becomes a thrust with the same general dip and strike. This latter may be seen in the isolated sandstone mountain, "Sugarloaf," 40 miles west of Washington. The perfect regularity, with which the folds become more and more abrupt toward the east, is at some points interrupted. On this section it is notably the case at Cumberland and Hancock, where a much sharper fold than the surrounding structure would lead one to expect discloses much lower horizons than are to be seen in the adjoining ridges (see the two sections beyond, figs. 5 and 6). Nevertheless, the regularity is so great as to have led so good a geologist as Rogers to the idea that the wave-like folds of the Appalachian system had been actually produced by undulations in a flexible crust due to horizontal pulsations or waves in the earth's liquid interior.[10]

Eruptive rocks in the gentler folds of the Appalachian system are noticeably absent. Along this section they are only to be found at all in the eastern portion, where the folds become abrupt or are replaced by faults and thrusts. Thus near Harpers Ferry and Weverton some ancient dikes occur, and the Blue Ridge sandstone (Lower Cambrian) is underlain somewhat farther north by large masses of ancient quartz-porphyries and rhyolites. More basic greenstones also occur in this region.*

*Am. Jour. Sci., 3d series. Vol. XLIV. Dec. 1892, p. 482.

The relation between the topography and drainage of the country and the geological structure is nowhere more apparent than in the Appalachian region, as was long ago pointed out by Lesley.[11] The drainage is consequent to the post-Carboniferous folding. The rivers in all probability flowed in the synclinal valleys. Many of the smaller streams follow the direction of the folds, while the larger ones, like the Potomac, Schuylkill, and Susquehanna, owe their transverse course to mutual reaction and adjustment through repeated cycles of elevation, tilting, and depression. This subject has been recently treated by Prof. William M. Davis in his studies of the rivers and valleys of Pennsylvania.[12]

The Piedmont Plateau.—For a distance of 43 miles after leaving Washington the railroad traverses, in a northwest direction, a rather low and rolling country, before entering the mountain belt proper at the station called Point of Rocks. It is composed of gneisses and mica-schists, sericite and chloritic schists, marbles and quartzites, whose strike follows in the main the general Appalachian trend. The relief of this country is given it by rapid streams or torrents, which are still excavating deep, rocky channels. The section of this belt affords a good idea of its general character, for although it increases greatly in width farther south, it everywhere retains a constant character at the eastern base of the Appalachians, and is for this reason appropriately designated the Piedmont plateau.

Topographically the Piedmont Plateau in Maryland and Virginia begins at the Catoctin Mountain, which meets the Potomac at Point of Rocks and pursues a straight course, across the former State, nearly northward from that point; geologically, however, the peculiar formations of still undetermined age, which are most characteristic of this region, begin farther to the east. At the base of Catoctin Mountain stretches a broad transgression of Triassic (Newark) red sandstone, which is crossed by the railroad at its narrowest point. From beneath the eastern border of this emerge the upturned edges of the Frederick Valley limestone, which has recently been found from its fossils to be the same as the Trenton-Chazy limestone which forms the valley farther west. East of this, with constant easterly dip, succeed overlying slates and another ridge of sandstone, which, however, only assumes topographical importance, as a high ridge, in the isolated mass of Sugarloaf. This mountain, seen just north of the railroad, is a thick monocline of easterly dipping beds, 1,350 feet in height. Geologically this mass forms the western boundary of the Piedmont plateau in Maryland. To it succeeds that vast complex of semicrystalline and holocrystalline rocks whose origin, age, and structure repeated earth movements have rendered most obscure. Along the section these extend eastward, becoming more and more crystalline, until they are buried beneath the overlying deposits of the Coastal plain.

The formations of this great Piedmont belt, and their equivalents farther north in New England, have, until recently, been usually classified as Archean. Very careful and detailed mapping is now, however, resulting in their subdivision, and in the identification of some as metamorphic Paleozoic strata, others as foliated eruptives, while still others belong really to the pre-Cambrian ages (Algonkian or Archean). It is to the detailed study of this field in Maryland and northern Virginia that the attention of the writer has of late years been directed. Some of his more general conclusions in regard to the structure of the Piedmont plateau have been communicated in a paper to the Geological Society of America.[13] The more important of these, as far as they relate to the region to be passed over, may be summarized as follows:

FIG. 4.—Section through the Piedmont Plateau in Maryland.

C = Catoctin sandstone; *N* = Newark (Triassic) red sandstone, with northwesterly dips; *L* = Frederick valley limestone; *Sh* = Hydromicaceous and chloritic schists; *Sl* = Slates; *D* = Mesozoic diabase dike; *D'* = Buck Lodge diabase; *D''* = diabase dike; *S* = Serpentine (two belts); *A* = Axis, near Derwood Station; *Gn* = Gneiss; *G*, *G* = Granitoid gneiss, with abundant inclusions; *G''* = Granite, in part hornblendic; *P* = Potomac clays and Coastal plain deposits.

The Piedmont plateau is divisible into an eastern highly crystalline and a western semicrystalline portion. The former consists of gneisses and holocrystalline mica-schists, quartzites and marbles, containing an abundance of more or less dynamically metamorphosed eruptive masses. All of these rocks have a prevailing NNE. strike and a westerly dip. The western portion, on the other hand, is composed of partially metamorphosed sedimentary strata (sericite and chlorite schists, ottrelite schist, phyllite and limestone) and is nearly free from ancient eruptives. The strike of these rocks conforms to that of the eastern portion, but their dips are prevailingly to the east. In spite of apparent conformity, and even indications of transitions between these two portions of the Piedmont region, they are separated by a great time-break and unconformity.

The easterly dips on the west, and the westerly dips on the east, together with the nearly vertical strata between, produce a radiating or fan structure, and the axis of this fan is *not* coincident with the contact between the crystalline and semicrystalline portions. The thickness of either series of rocks, as indicated by their present dips, would be so vast that one must assume that the same beds are repeated over and over again by tightly compressed folds or thrusts.

The adjoining section (Fig. 4) made along the line of railroad between

Washington and Point of Rocks will illustrate the general character of the Piedmont plateau about the latitude of Washington.

In the absence of all paleontological data, it is impossible to assign a definite age to either of these series. In the light of what has been discovered elsewhere, however, it is not improbable that the western and semicrystalline areas represent the older Paleozoic horizons, metamorphosed by more intense dynamic action than has affected them farther west, while the holocrystalline rocks on the east are a remnant of the pre-Cambrian continent, from which the Paleozoic sediments were derived.

The apparent conformity between the two regions may be explained by supposing that the highly crystalline rocks also formed the floor upon which the now semicrystalline schists were deposited as sediments. These older rocks, already greatly altered and folded, underwent at the time of the Appalachian uplift one more final folding, which gave them their now prevailing trend, and carried the overlying Paleozoic sediments with them. This supposition is also in accord with the fact that several closed synclinals of slate and semicrystalline schists are found pinched into the gneisses, far to the east of the main contact.

WASHINGTON, D. C., TO CUMBERLAND, MD.

ITINERARY.

By G. H. WILLIAMS.

Station.	Distance. Miles.	Distance. Kilometers.	Elevation. Feet.	Elevation. Meters.	Station.	Distance. Miles.	Distance. Kilometers.	Elevation. Feet.	Elevation. Meters.
Washington *	0	......	10	3	Washington Junction	43	69	229	70
Terra Cotta	4	6	......	......	Point of Rocks	43	69	......	......
Silver Spring	7	11	......	......	Weverton	52	84	249	76
Garrett Park	12	19	......	......	Harpers Ferry	55	89	272	83
Rockville	16	26	......	......	Martinsburg	74	119	634	193
Derwood	19	31	......	......	North Mountain	81	130	547	167
Gaithersburg	22	35	......	......	Cherry Run	87	140	398	121
Boyd	30	48	......	......	Hancock	96	154	474	143
Dickerson	36	58	......	......	Cumberland †	152	245	639	195
Tuscarora	39	63	......	......					

* Population, 230,392. † Population, 12,729.

Washington. On leaving Washington, the railway line at first passes over the unconsolidated deposits of the Coastal plain. The lowest of these is the Potomac series (of early Cretaceous or late Jurassic age), consisting of coarse littoral conglomerates at the base, formed of well-rounded pebbles of quartzite. Above the conglomerates are a series of variegated clays, often valuable for pottery, and sometimes containing deposits of limonite.

Terra Cotta. At this station are works where drain pipes, etc., are made from the clays of the Potomac series.

Silver Springs, on the northern boundary of the District of Columbia. The rock here is a very granitoid, though much rotted, gneiss. It is not visible from the cars. The road then passes over typical holocrystalline gneiss, with steep westerly dips, to

Garrett Park, where these are cut by serpentine and a still later hornblende granite, filled with included fragments of the surrounding gneiss.

Rockville, a thriving town, recently much developed as a suburban residence part of Washington. The division between the crystalline and semicrystalline portions of the Piedmont plateau passes just west

of here. The rock near the station is a nearly vertical feldspathic gneiss, but just beyond the sericite schists are seen.

This place is directly north of the Great Falls of the Potomac, the source of Washington's water supply, near which the gold mines of Montgomery County are situated.

Derwood is where the schists are quite vertical, and where the axis of the Piedmont fan crosses the road (see section Fig. 4).

Gaithersburg. Here are several lenses of serpentine in the schists; the latter are fully exposed in the deep ravine of Great Seneca Creek.

Boyd. Here a large mass of intrusive trap occurs, which is petrographically identical with the Triassic dike of diabase just west of it. The age of both is in all probability the same.

Dickerson. The isolated mass of Sugarloaf Mountain, which has for some time been visible, is now well seen on the right (north). It is an east dipping monocline of sandstone, divided into two parts by a longitudinal valley, and is probably due to a double thrust of the sandstone from the east. Near this point, also, a broad transgression of Triassic red sandstone is entered, and a little beyond a great dike of diabase is cut through. This latter traverses the whole State of Maryland from north to south, and passes into Virginia. Its hardness makes it a topographical feature, which is known in the neighborhood as "Ironstone Ridge." A mile or so farther, the Monocacy River is crossed by a high bridge; a short break in the red sandstone exposes the shales and blue limestone of Frederick Valley (Hudson and Trenton), which at the railroad are mostly covered by alluvium deposited by the Potomac River, which is here for the first time approached.

At **Tuscarora** red sandstone appears again and continues to **Washington Junction.** For a mile or more before reaching the latter station the upper member of the Trias is well exposed along the line of the railroad. This is a coarse conglomerate of rounded, or sometimes angular and broken, pebbles of variegated Paleozoic limestone, embedded in a red argillaceous matrix. It is a striking rock and enjoys quite a wide celebrity as a decorative stone. It is known as "Potomac Marble," or "Calico Rock," and is the material from which the great columns in the rotunda of the Capitol at Washington were made.

At this point (**Washington Junction**) connection is made for the city of Frederick, some 15 miles to the north, which occupies the center of the broad, fertile limestone valley. Before reaching this place, however, the main line of the Baltimore and Ohio railroad diverges and pursues a course down the Patapsco River direct to Baltimore. Near this point of divergence, on the Monocacy River, 12 miles NE. of **Washington Junction,** an important battle of the war was fought in 1864, and the northern extension of the same valley in Pennsylvania was the scene of the great battle of Gettysburg.

Point of Rocks, a short distance beyond **Washington Junction**, marks the entrance of the Appalachian Mountain belt proper. The river here cuts through a high ridge capped by a monocline of Cambrian sandstone, known as Catoctin Mountain. This runs nearly due north and forms the western boundary of the Frederick Valley. The road passes for 8 miles across a valley of slate, drained by Catoctin Creek, and called, from its principal town on the Maryland side of the river, the Middletown Valley. It then intersects another abrupt ridge nearly parallel to Catoctin Mountain at

Weverton. This is the junction for a branch road northward to Hagerstown, one of the largest cities of Maryland. The road now crosses a slight depression occupied by crystalline rocks (granite-gneiss with some basic dikes) and soon reaches

Harpers Ferry, a place which, both geologically and historically, is of more than usual interest. From the railway bridge over the Potomac may be seen on the right (north) a lofty ridge of contorted sandstone with underlying shales and slates, known as Maryland Heights. Upon the opposite side of the river rises the continuation of this ridge in Virginia, known as Loudoun Heights. The course of the Potomac is for some distance above this point nearly south, and here it is joined by one of its most important tributaries, the Shenandoah River. In the triangular space between these two streams lies the town of Harpers Ferry, which, from its surroundings, possesses great strategic importance.

The two ridges cut through at **Weverton** and **Harpers Ferry** well illustrate a characteristic feature in Appalachian topography. The former originates a short distance south of the river and continues its course across Maryland as the "Blue Ridge," and, after its junction with the Catoctin Mountain, as "South Mountain," in Pennsylvania. The Harpers Ferry elevation, on the other hand, soon dies out toward the north, but continues its course hundreds of miles southward, across Virginia and North Carolina, as the "Blue Ridge." Thus, near the Potomac, one important fold dies out and is continued by another, *en echelon*, or offset somewhat to one side, as is a frequent occurrence among the long parallel ridges of the Appalachian system.

The geology at **Harpers Ferry** is complex, and has given rise in former times to different interpretations by different investigators. To the west are the contorted layers of the blue Valley limestone, known from its fossils to be of Trenton-Chazy age (11). On the east of these, and apparently overlying them, succeeds a thick mass of shales, slates, and the contorted sandstones seen in the front face of Maryland Heights which Walcott has recently shown to be Lower Cambrian. Then follows toward the east, occupying the space between here and

Weverton, the axis or base of granite-gneiss, whose cleavage dip (undoubtedly a secondary feature) is constantly toward the east.

Beyond **Harpers Ferry** the railroad temporarily leaves the river and crosses the broad Shenandoah Valley. This is composed of the same Trenton-Chazy limestone as the Frederick Valley, and is possessed of a like fertility. Its continuation southward is the great "Valley of Virginia," notable for its caves (Luray and Wiers), its "natural bridge," and for the fact that it is just now the scene of remarkable industrial activity and development, by which the richness of its natural resources is being rapidly brought to light.

At **Martinsburg**, the largest place passed by the railroad in this valley, there are shales of Hudson River age (III), developed by a fold in the limestone.

At **North Mountain** the great valley is left for another intersection of a sandstone ridge, while to the north of the next station,

Cherry Run, there occurs a great fault by which rocks of all the formations, from the Niagara (V) to the Hamilton (VIII), inclusive, are brought successively in contact with the Trenton-Chazy.

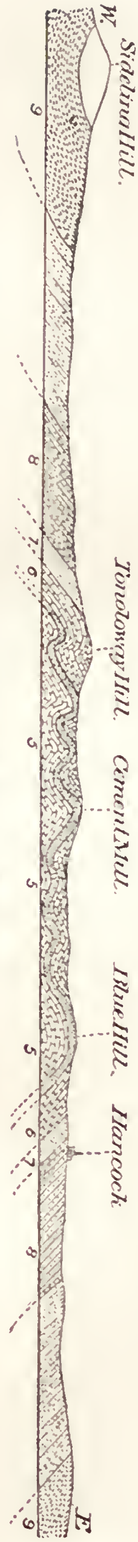


FIG. 5.—Section near Hancock, Maryland.

Hancock is a town of some importance, situated at the narrowest part of Maryland, where the State is not over 4 miles wide. It was formerly a prominent station of the National turnpike; its chief industry now is the manufacture of cement from the Helderberg limestone (VI). Here occurs one of the more abrupt anticlinal folds mentioned above, whereby the whole sequence of Upper Silurian and Devonian formations is exposed on either side of a wide compound arch (fig. 5). At the railway station fossiliferous shales are exposed.

Within the next 3 miles westward, Oriskany sandstone (VI), Helderberg limestone (cement rock), and the red Salina sandstone band at its base, are traversed. At 3 miles from the station the cement mills are situated, and near them are some small folds of the Salina rock of remarkable perfection. The center of one of these was used one hundred years ago as a blacksmith's forge, and it is not ill-suited for this purpose.

Between **Hancock** and **Cumberland** the road follows the remarkable sinuosities of the river for 56 miles to accomplish a distance which, in a direct line, is only 32. Within

FIG. 6.—Section near Cumberland, Maryland.

this distance the track crosses, more or less obliquely, several rather low and flat folds of Upper Silurian and Devonian strata, and finally reaches

Cumberland. Although it contains but 13,000 inhabitants, this is the largest place in Maryland, next to Baltimore. It has considerable importance as the center of the coal industry of western Maryland and from the manufacture of Portland cement of excellent quality. Geologically, Cumberland is important because it affords one of the most complete sections of the entire Paleozoic series to be found anywhere within the Appalachian system. This is not seen to the best advantage along the railroad line, which here enters upon a southwesterly course, but by following up Wills Creek and Jennings Run, which head in the Frostburg coal basin. On the west side of the town rises an abrupt N. to S. ridge, Wills Mountain (fig. 6). This is composed of red layers of the lower Medina (IV), capped by the massive white bed of the same horizon, which forms an anticlinal fold whose eastern flank dips gently east while its western plunges downward nearly vertically. On the east side of this axis, in the city itself, may be seen in succession Clinton, Niagara (V), Salina, Helderberg (VI), Oriskany (VII), and Hamilton beds (VIII), all filled with their characteristic fossils. On the west side of the mountain, owing to its abrupt downward plunge, the series is still more complete and extends, within a short horizontal distance (8 miles), to the top of the Coal Measures.

Above **Cumberland** the road follows the river in a southwest direction as far as **Keyser**, parallel with the strike of the beds, and along the west base of Knobby Mountain. This mountain is made of Salina and Helderberg beds, capped by Oriskany sandstones, which are visible in the cliffs. On the right (west) can be seen the first range of the Alleghany Mountains, which is capped by the Pottsville conglomerate (millstone grit), the Mountain limestone, Pocono sandstone and Chemung beds forming the intervening slopes, while the valley at the base is in Hamilton shale.

At **Bradys**, in limestone concretions of the Helderberg limestone, have been found beautifully and curiously developed crystals of celestite.[14]

On the left, before entering the town of **Keyser**, are quarries in Helderberg limestone, and on the right, cliffs of

Oriskany sandstone. Beyond **Keyser** the road crosses the Potomac into West Virginia, and fine exposures of Hamilton shales are seen in the cuts. The road now bends to the northwest and crosses, at right angles to the strike, steeply dipping beds of the Devonian and of the Carboniferous up to the Coal Measures, a thickness of about 13,000 feet (4,000 m.) of rock strata.

FROM CUMBERLAND (MD.) TO THE OHIO RIVER.

By I. C. White.

The area across which the Baltimore and Ohio Railroad passes from Cumberland westward to the Ohio River includes all of the Alleghany Mountain country proper, and also about three-fifths of the breadth of the great Appalachian coal field, the eastern line of which is found only five miles northwest from Cumberland, and the western margin of the same near Newark, Ohio. The air-line distance across the Appalachian field along the line of the Baltimore and Ohio Railroad is about 164 miles, but the distance by rail between Cumberland and Newark, the two margins of this coal field, is 315 miles.

Fig. 7—Section across the Alleghany Mountains to the Ohio River.

15 Permian. 14^c Upper Coal Measures. 14^b Lower Coal Measures. 14^a Millstone grit. 13^b Mountain limestone and Mauch Chunk shales. 13^a Pocono Sandstone. 12 Catskill. 11 Chemung.

As shown by the above illustration of the geological structure, the rocks of the Alleghany Mountain country are crumpled up into a series of large folds, and these, together with the great erosion to which the region has been subjected, have produced the wild and rugged scenery between Piedmont and Rowlesburg.

The Pottsville Conglomerate (XII), and the Pocono sandstone (X) are the mountain-makers of the Alleghanies, while the great anticlinal ridge (Wills Creek Mountain), through which the Baltimore and Ohio Railroad leaves Cumberland for Pittsburg, is made by the White Medina sandstone (IV) at the base of the Upper Silurian.

Westward from the Alleghanies proper the folds in the strata become gradually more gentle, and finally die away, before reaching the Ohio River, into low undulations of the beds, which are so insignificant as to be almost imperceptible to the eye.

The great arches already referred to bring up the lowest rocks of the region in the vicinity of Cumberland, so that from there westward we pass upward through the geological scale from the middle of the Medina

series in the Wills Creek gap at Cumberland to the summit of the Permo-Carboniferous, or Permian, beds in the middle of the great plateau between the Monongahela and Ohio rivers.

The character of these several terranes and their thicknesses, etc., along this line, will now be briefly described in ascending order.

Medina series (IV of Rogers, base of Upper Silurian), thickness 2,055 feet.

	Feet.
(*a*) Oneida Conglomerate	355
(*b*) Red Medina	1,200
(*c*) White Medina	500

The thickness of the Red Medina and the Oneida beds in the above measurement is based upon data obtained from a deep boring in Wills Creek gap, one mile east from Cumberland. The well starts 790 feet above the base of the Red Medina, penetrates the Hudson River dark shales at 1,145, and stops in them at 2,010, probably about 1,000 feet from the top of the Trenton limestone.

The White Medina is finely exposed in the great arch of Wills Creek Mountain, where its top rises to 1,300 feet, almost vertically, above the bottom of the gorge through which Wills Creek finds an exit to the North Potomac River at Cumberland.

This great arch dies rapidly away to the northwest and the Medina passes below the surface where the North Potomac passes across its trend 15 miles southwest from Cumberland, but 10 miles farther southwest the arch swells up again, and the Medina coming above the surface makes the summit of New Creek Mountain. This rock is the great mountain-maker of the Appalachian belt east from the Alleghanies and west from the Blue Ridge, and on account of its hardness is highly valued for ballasting railroad tracks.

Clinton series, (*V*) thickness 721 feet.

	Feet.
(*a*) Lower olive shales	100
(*b*) Iron sandstone	20
(*c*) Middle shales and limy beds	300
(*d*) Fossil iron ore	1
(*e*) Upper limestones and shales	300

The Niagara limestone proper has never been differentiated from the great mass of limy shales and impure limestones which occur in the interval between the Salina series and the Medina sandstone, anywhere along the Appalachian system. It is possibly absent, but until the richly fossiliferous beds which are here grouped under the Clinton are thoroughly studied, no one can say positively that the Niagara limestone of the New York column is not represented in the series of rocks given above and all classed as Clinton.

This series is beautifully exposed at Cumberland, along the Pennsylvania Railroad, near the southern entrance to Wills Creek Gap. The

"fossil ore" (*d*) was once mined here, and has the same appearance and fossils as in New York and Pennsylvania.

Salina series, (*VI*) thickness 680 feet.

	Feet.
(*a*) Red shales and thin, light-colored limestones with marly shales	300
(*b*) Water lime, a bed of dark, magnesian limestone, from which the famous "Cumberland cement" has long been manufactured; finely exposed at the quarry along the West Virginia Central and Pennsylvania railroads in Cumberland, thickness	30
(*c*) Gray and yellowish, thin-bedded, sparingly fossiliferous, impure limestones	350

Lower Helderberg series (*VI*), thickness about 350 feet.

Massive gray and dark-colored limestones, many of the layers quite pure, and a splendid flux for iron ores, richly fossiliferous; finely exposed at **Cumberland**, and from there southwestward to **Keyser**, a distance of 24 miles.

Oriskany sandstone (*VII*), thickness 75 to 100 feet.

A coarse, dirty yellow, calcareo-siliceous rock, highly fossiliferous (mostly casts); makes Knobby Mountain, which starts at Cumberland and trends away to the southwest; often forms great cliffs along the Baltimore and Ohio Railroad, between **Cumberland** and **Keyser**; one of these just east from **Keyser** is known as Bull Neck, and here the railroad passes across the Oriskany in a cut through a sharp syncline, making a fine exposure of the rock and its fossils. The high cliff just opposite **Keyser**, across the Potomac River from the Baltimore and Ohio station, is made by this rock, and is known as Queens Point. From **Cumberland** eastward this stratum is quite massive and often forms ridges 1,000 to 1,200 feet high.

At **Cumberland** the Baltimore and Ohio Railroad, main line, turns southwestward, following up the North Potomac River, and hence runs along the strike of the rocks to **Keyser**, 21 miles from **Cumberland**, so that not only the Oriskany sandstones, but all of the other beds below it, down to the Medina white sandstones, are frequently seen between the two points.

The Corniferous limestone appears to be absent entirely from the Alleghany Mountain region, since although a thin, earthy limestone (Selinsgrove) is present a few feet above the Oriskany at many points, it evidently belongs to the Marcellus epoch of the Hamilton.

Hamilton shales, (*VIII*). A series of black slates, olive shales, and dark gray sandy beds, with an earthy limestone near the base, all quite fossiliferous. These beds underlie the station site in **Cumberland**, and are partially exposed just east from it in a cutting; also exposed in the vicinity of **Keyser**.

These rocks make valleys wherever they extend, and hence are usually covered up and concealed from view by soil and detrital matter, so that the exact thickness can not be determined, but estimating

this from the usual breadth of the valleys, and dip of the hard rocks above (Portage) and below (Oriskany), if no rolls are present, the entire thickness of the Hamilton rocks, including Marcellus, Hamilton proper, and Genesee, in the region of **Cumberland** and **Keyser**, can not be less than 3,000 feet.

Chemung Series, (*VIII*). Total thickness 5,000 feet.

The Portage beds consist of olive gray shales and flaggy layers, sparingly fossiliferous; thickness probably about 1,000 feet.

The Chemung beds consist of olive shales, flaggy sandstones, and one massive conglomerate (Allegrippus) near the top; thickness about 2,500 feet.

The Catskill beds are a series of reddish shales, green and red sandstones, with conglomerate layers in lower half; thickness 1,500 feet.

The Chemung* rocks have a fine development along the line of the Baltimore and Ohio Railroad, east as well as west from **Cumberland.**

West from **Cumberland** the first exposure of these beds is about two miles west from **Keyser**, where the Chemung proper is fairly well exposed, dipping down under the great trough of the Cumberland coal basin. Then follow the red shales and sandstones of the Catskill, but the latter reappear along the Savage River after the railroad has crossed the Potomac coal basin and begins the long climb up the "17-mile" grade to the summit of the Alleghany Mountains at **Altamont.** The Catskill beds are covered up by the Pocono (Lower Carboniferous) sandstones in the summit cut at **Altamont**, but reappear just west from it and extend along the Baltimore and Ohio to **Deer Park** and a mile beyond, where the Negro Mountain anticlinal, which crosses the Baltimore and Ohio at **Mountain Lake Park**, 3 miles west of **Deer Park**, brings up the soft shales and conglomerates of the Chemung proper. Then these beds turn over and descend under the Youghiogheny River coal basin, to be brought to the surface again on the crest of another great arch at **Terra Alta**, and are constantly in sight from there down the western slope of the Alleghanies to Cheat River, at **Rowlesburg**, and two miles beyond, where the red Catskill beds pass under water level, to be seen no more to the west.

Pocono sandstone (*X*), *Lower Carboniferous.*

	Feet.
Thickness near Piedmont about	1,000
Thickness on Cheat River, near Rowlesburg	600
Thickness at Mannington	400

A series of hard, gray, current-bedded sandstones, usually of rather fine grain, but occasionally containing flat pebble conglomerates, inter-

* The term *Chemung* as here used includes the three epochs of Portage, Chemung, and Catskill, as proposed by Dr. Jno. J. Stevenson in his vice-presidential address before Section E, at the Washington meeting of the "A. A. A. S.," August 1891.

stratified with sandy shales, comes next above the Catskill red beds. The series is first seen on the Baltimore and Ohio between **Keyser** and **Piedmont**, where it has a thickness of 1,000 feet, and makes the east front ridge of the Alleghany Mountain, on the south side of the Potomac, and Dan's Mountain, on the north side, but soon dips rapidly down under the Cumberland coal basin.

These beds come up again a few miles west from **Piedmont** and are seen making the steep upper escarpment of Big and Little Savage mountains, westward to the top of the "17-mile grade" at the summit of Back Bone Mountain, near **Altamont**, where the highest cut, at 2,620 feet elevation, is through these sandstones.

It is seen again at **Oakland**, making a fine cliff near the Baltimore and Ohio hotel, and dipping down under the Youghiogheny coal basin, to come up and pass into the air just east from **Terra Alta**, and then, coming down again, makes the summit of Briery Mountain, the most western ridge of the Alleghany range, and, passing under the Baltimore and Ohio Railroad for the last time just west of **Rowlesburg**, assists in shaping the grand scenery along the Cheat River gorge between **Buckhorn Wall** and **Rowlesburg**.

The upper portion of this sandstone series is the great oil and gas depository of West Virginia; at **Mannington**, on the Baltimore and Ohio Railroad, where this stratum lies 1,800 feet below the surface, a large oil field, extending northeast to the Pennsylvania line and southwest for an unknown distance, has been developed in these beds.[15]

Mountain limestone and Mauch Chunk red shale (*XI*).—This subdivision of the Lower Carboniferous, like the Pocono beds below, is more closely allied to the Catskill series, both in its lithological aspects and in its fossils, than to the Coal Measure series above, which always rests unconformably upon it.

The bottom member of the series, the Mountain limestone, where crossed by the Baltimore and Ohio, just east of **Piedmont**, is 340 feet thick, quite fossiliferous, and consists of gray limestone interstratified with marly gray shales, and some red beds, the lowest 30 feet being a silicious limestone merging gradually into the Pocono sandstone below. On Cheat River, west from **Rowlesburg**, where the Baltimore and Ohio grade cuts through this series, it is 273 feet thick, of which the silicious member at its base measures 105 feet. West from **Rowlesburg** the Mountain limestone is seen no more, but at **Mannington** the drill passes through it at 1,600 feet below the surface, where it is 90 feet thick, while at **Bellaire** it is still 30 to 50 feet thick, as determined by drill holes. As is well known, this Mountain limestone thins away entirely, to the northeast along the Alleghanies, and is not found anywhere in northeastern Pennsylvania, but southwest from the Baltimore and Ohio Rail-

road it thickens greatly, attaining 900 feet in Randolph and Pocahontas counties, W. Va., 1,100 feet in Greenbrier County, and on New River, in Summers County, a deep boring, 12 miles above Hinton, finds it 1,415 feet thick.

The Mauch Chunk Red Shale division of No. XI consists of bright red shales, impure limestones, and massive, green sandstones, and frequently contains iron ore near the top in irregular layers and nuggets. The thickness of this series on the Baltimore & Ohio near **Piedmont** is 850 feet, but on Cheat river, near **Rowlesburg**, it is reduced to only half that amount, or 440 feet, while westward from this latter locality the Mauch Chunk continues to dwindle in thickness, being only 140 feet in the oil borings at **Mannington**, and probably not more than half of this at **Bellaire** on the Ohio river, while further northwest in Ohio it seems to disappear completely.

These beds are quite variable in thickness along the Appalachian Mountain region, being 3,000 feet at Mauch Chunk, Pa., and about 2,500 in Greenbrier county, West Virginia. Like all of the Paleozoic deposits, they attain their maximum thickness to the east, and diminish rapidly westward. The flora of these beds seems to be more closely related to that of the Catskill below than to that of the Coal Measures above.

The Pottsville Conglomerate, Millstone Grit, etc. (*XII*).[16]—The basal member of the Coal Measures, rests unconformably (not in dip but by erosion) upon the underlying Lower Carboniferous beds, and consists of white, hard, and often conglomeritic sandstones, interstratified with dark shales which contain coal beds (New River series), thin and insignificant along the Baltimore & Ohio Railroad and elsewhere to the northeast, but thickening up to the southwest, and becoming the famous coking and fuel coals of New River, West Virginia, and the Pocahontas region of Virginia and West Virginia.

The sandrocks of this series, being composed of nearly pure quartz grains and therefore almost indestructible by atmospheric agencies, have played a very important part in forming the wild scenery along the Alleghanies; in fact, this series conspires with the Pocono beds below to make the Alleghanies, the Pottsville beds topping out the highest summits, like Eagle Rock near **Deer Park**, on the "backbone" of the Allgehanies (3,350 feet). The wild scenery where the Baltimore and Ohio passes out of the Cheat river canyon, west from **Rowlesburg**, is made principally by these beds. Wherever these rocks come to the surface, they form "rock cities," waterfalls, canyons, mountains, and a rugged, picturesque country generally. The series varies greatly in thickness, as will be seen by the following:

Thickness on the B. and O. R. R.:	Feet.
Near Piedmont	473
Near Oakland	700
Near Rowlesburg	362
At Mannington	255
At Bellaire	200
Thickness at Pottsville, Pa	1,000
Thickness on New river, W. Va	1,400

Lower Coal Measures, Alleghany River Series (XIII).[16]—The next higher series of rocks, called the Alleghany River Coal Series, contains the greater portion of the coal in the Appalachian field. These measures consist of alternate beds of coal, shale, limestone, and sandstone, and where the Baltimore and Ohio Railroad first crosses them at **Piedmont, West Virginia**, have a total thickness of 308 feet; 310 feet near **Rowlesburg**; 225 feet in the deep shaft at **Newburg**; 262 feet at Nuzum's, 10 miles west of **Grafton**; and 220 feet at the Ohio river near **Bellaire.**

In Pennsylvania this series has a thickness of 200 to 370 feet, while in Ohio the same series varies between 175 and 250 feet. In northern West Virginia these measures are 200 to 300 feet thick, but they thicken rapidly to the southwest, and on the Big Kanawha, at Powellton, are 1,000 feet, and maintain that southwest from there to the Tug river in Logan county.

The principal coal beds of this series are the following in ascending order:

(*1*) *Clarion.* (*2*) *Lower Kittanning.* (*3*) *Middle Kittanning.* (*4*) *Upper Kittanning.* (*5*) *Lower Freeport.* (*6*) *Upper Freeport.*

The Barren Measures, Elk River Series (XIV).—The Barren Measures occupy the interval between the Upper Freeport coal and the next great coal bed about 600 feet above, viz, the Pittsburg seam. This Elk River Series contains several (5) coal beds, but the most of them are too thin and impure to be commercially valuable, with the exception of the two lower ones (Mahoning and Masontown). The rocks consist of massive sandstones, red shales, and thin limestones. Marine fossils occur for the last time about the middle of this series at the horizon of the Crinoidal limestone, since above that stratum nothing but brackish or fresh water forms are found. These beds furnish valuable building stone (Mahoning, Morgantown, and Connellsville sandstones), and make a great band of red soils from western Pennsylvania clear across West Virginia into Kentucky, and back around through southern Ohio to western Pennsylvania.

This series is, in the hills at **Piedmont**, about 500 feet thick. Where next found on the Baltimore and Ohio Railroad, at **Newburg**, these rocks are 650 feet thick, and the railroad runs in them from there to **Fairmont**, except for a short distance on the crown of the Chestnut Ridge axis, 10 miles west of **Grafton**.

The fauna of this series belongs to extreme Upper Carboniferous types, and some forms are closely related to Permian species, while the flora above the middle of the series is also of Permian aspect.

	Feet.
Maximum thickness (on the Great Kanawha in West Virginia)	800
Minimum (in Ohio)	400
Average thickness	600

The Upper Coal Measures, Monongahela River Series (*XV*).—These beds crown the summit of the mountain in the bottom of the syncline at **Piedmont**, the principal coal (the Pittsburg) being known there as the "Big" bed, since along George's Creek, between **Piedmont** and Frostburg, it is often 20 feet thick, and is mined and shipped under the name of Cumberland coal. This great bed of valuable fuel is the basal member of the Upper Coal Measures, and is the most important stratum in the Appalachian field. It is the celebrated Connellsville coking coal, the Westmoreland and Penn gas coal, the shipping coal all along the Monongahela River, and extends under a vast area between that stream and the Ohio River.

A small remnant of it is found in the summits of the hills at **Newburg**, and the Baltimore and Ohio Railroad does not cross its outcrop again until we come to the town of **Fairmont**, where, at Monongah, Gaston, Montana, and West Fairmont, it is extensively mined for coking, gas, and general fuel purposes.

Westward from **Fairmont** it dips down below water level, being 400 feet below the valley at **Mannington** and 800 feet at **Board Tree**, where it is 1,500 feet under the highest summits. Rising westward from the center of the great Appalachian trough at **Board Tree**, it comes to the surface again at **Bellaire** and furnishes valuable fuel for that city and **Wheeling**.

The rocks above the Pittsburg coal in Pennsylvania, northern West Virginia, and Ohio are mostly limestones and calcareous shales, with some sandstone, and four other coal beds, viz, in ascending order:

Redstone. Sewickley. Uniontown. Waynesburg; this last topping out the series.

Southwestward through West Virginia and southern Ohio, the limestones are replaced by red shales and the last four coals practically disappear, while much massive sandstone comes into the column.

This series has an average thickness of 360 feet along the Monongahela river, but it thins to 250 feet in Ohio and thickens to 413 feet in the central portion of the Appalachian trough.

The Permian, Dunkard Creek Series (*XVI*).—This series of beds tops out the Carboniferous system in the Appalachian field, and has its greatest development along the Baltimore and Ohio Railroad between

the Monongahela and Ohio rivers. The series begins with the roof shales of the Waynesburg coal, and includes all of the beds above, about 1,100 feet in all. It consists of massive sandstones, red and variegated shales, with thin limestones and impure, mostly worthless, coal beds.

The fauna has never been studied, but appears to be of fresh-water origin, and is largely composed of bivalve crustaceans, while the flora has a distinctly Permian facies, containing *Callipteris conferta*, *Saportæa*, *Tæniopteris*, *Baiera*, and other Permian types, while the species that resemble Coal Measure forms also occur in the Wichita, or undisputed Permian of Texas, so that the evidence is now complete that this Dunkard Creek series, formerly called Permo-Carboniferous, is the American equivalent of the European Permian.

Tabular view of the geology between Cumberland and the Ohio River.

[By I. C. White.]

Station.	Distance from Washington.		Elevation.		Geological formations.
	Miles.	Kilometers.	Feet.	Meters.	
Cumberland	152	245	639	195	Medina to Hamilton.
Bradys Mill	159	256	642	196	Lower Helderberg.
Potomac Bridge	172	277	786	240	Hamilton.
Keyser	175	282	800	244	Lower Helderberg to Hamilton.
Piedmont	180	290	925	282	Pottsville to Dunkard Creek series.
Bloomington	182	295	1,024	312	Pottsville to Elk River series.
Frankville	188	303	1,699	518	Catskill to Pottsville.
Altamont	197	317	2,620	799	Pocono to Pottsville.
Deer Park	200	322	2,442	744	Chemung to Catskill.
Mountain Lake Park	203	327	2,400	731	Chemung.
Oakland	206	332	2,372	723	Catskill to Pocono.
Little Youghiogheny Bridge.	206½	333	2,371	723	Mauch Chunk.
Great Youghiogheny Bridge.	207	333	2,372	723	Pottsville conglomerate.
Huttons	212	541	2,477	755	Lower Coal Measures.
Snowy Creek	214	344	2,469	753	Mauch Chunk.
Terra Alta	216	348	2,549	774	Chemung, western ridge of Alleghanies.
Rodemer's tunnel	220	354	2,083	635	Catskill.
Cheat River Bridge	227	367	1,392	424	Chemung to Catskill.
Rowlesburg	227	365	1,392	424	Do.
Buckeye Run	228	367	1,515	462	Catskill.
Buckhorn Wall	231	370	1,720	524	Mauch Chunk and Pottsville.
Cassidys Summit	233	374	1,855	565	Top Lower Coal Measures.
Tunnelton	234	375	1,820	555	Do.
East portal, Kingwood tunnel.	234	375	1,819	554	50 feet under Upper Freeport coal.
West portal, Kingwood tunnel.	235	378	1,779	542	Upper Freeport limestone and coal.
Murray's tunnel	238	383	1,554	474	Upper Freeport coal at track level.

Tabular view of the geology between Cumberland and the Ohio River—Continued.

Station.	Distance from Washington.		Elevation.		Geological formations.
	Miles.	Kilometers.	Feet.	Meters.	
Newburg	241	388	1,215	370	Elk River series; Pittsburg coal in hill-top; shaft through Lower Coal Measures.
Independence	242	389	1,156	352	Elk River series (No. XIV).
Raccoon Creek	244	392	1,105	337	Do.
Thornton	248	399	1,038	316	Do.
Grafton	254	409	987	301	Do.
Fetterman	255	410	984	300	Do.
Valley River falls	261	420	969	295	Pottsville to Elk River series.
Texas	268	431	883	269	Elk River series (No. XIV).
Fairmont	276	444	877	267	Do.
Barnesville	277	444	871	265	Upper Coal Measures.
Dunkard Mill run	284	458	922	281	Waynesburg coal, 150 feet above track; Pittsburg coal, 230 feet below track.
Mannington	293	476	957	292	Base of Permian; Pittsburg coal, 400 feet below valley; oil field here in Pocono S. S., 1,800 feet below valley.
Glovers Gap	300	483	1,050	320	Permian.
Glovers Gap tunnel	302	486	1,146	349	Permian, 900 feet above Pittsburg coal.
Burton	304	489	1,060	323	Permian.
Hundred	306	492	1,025	312	Permian, 700 feet above Pittsburg coal.
Littleton	311	500	936	285	Permian.
East portal, Board Tree tunnel.	314	505	1,104	336	Permian; center of Appalachian trough; 1,100 feet Permian beds.
West portal, tunnel	314¾	506	1,077	328	Permian.
Bellton	318	512	886	270	Permian; Belton coal group.
East portal, Welling tunnel.	323	520	1,202	366	Permian
Cameron	325	524	1,049	320	Permian; natural gas here in Gordon oil sand, 2,700 feet below valley.
Easton	330	531	967	294	Permian.
Rosbys Rock	336	543	773	236	Do.
Moundsville	342	550	640	195	Upper Coal Measures, Pittsburg bed, 125 feet below track level.
Benwood	349	562	648	197	Pittsburg coal at track level.
Bellaire	350	573	657	200	Do.
Wheeling	353	568	645	197	Pittsburg coal 60 feet above track level.

FROM THE OHIO TO THE MISSISSIPPI RIVER.

GENERAL SKETCH.

By G. K. Gilbert.

This is for the most part an area of Paleozoic strata lying nearly horizontal. The Coal Measures constitute the underlying rocks from Bellaire on the Ohio River to Newark, Ohio. The lower members of the Carboniferous constitute the underlying beds from Newark to a point just west of Chicago Junction, Ohio. From this point to Tiffin, Ohio, the Devonian rocks underlie. From Tiffin to a point west of New Baltimore the region is underlain by Upper Silurian rocks. From New Baltimore, Ohio, to a point west of Union Mills, Ind., the Devonian rocks again constitute the substructure; and from the last-named point to Watertown, Wis., the Upper Silurian terrane underlies the drift. From Watertown, Wis., for a few miles the Lower Silurian rocks come to the surface, except where concealed by drift, and thence to La Crosse the Cambrian rocks appear. The disturbance of these strata throughout the region of the route is so slight that it nowhere expresses itself in well-marked surface features.

The greater part of the route is through a region overspread with glacial drift, the southern part of the great North American glaciated area. From near Newark, Ohio, to Kilbourn City, Wis., the older formations are generally concealed by the drift deposits. The surface features by which this region is characterized and by which it is distinguished from the territory south of the limit of glaciation include an imperfect drainage system abundant in lakes, lakelets, ponds and marsh meadows, and the replacement of the topographic forms developed by subaerial erosion by the less regular but equally characteristic forms of glacial deposit.

The layer of drift ranges from a few feet to several hundred feet in thickness, and its most important element is till or boulder-clay. It is exhibited in a general sheet of ground moraine, traversed by relatively thick bands of the nature of terminal moraines. The moraines are usually several miles broad and their ensemble is not commanded by the tourist, who is able only to observe changes in the topographic character of the country as he enters and leaves their belts. The surfaces of terminal and ground moraines are alike undulatory, but the slopes of the terminal moraines are relatively steep. Hillocks, often somewhat elongated, alternate rapidly with hollows for the most part

undrained. The more elongate hills of the terminal moraines are apt to lie parallel to the course of the moraine; the hills of the ground moraine usually trend parallel to the direction of ice movement. Associated with the terminal moraines are many hillocks and abrupt ridges of water-worn and assorted gravel and sand, and sometimes these water-wrought materials sheathe parts of the moraine where its core is of boulder-clay.

In low and level tracts the *till* proper is frequently covered with sand or silt. Many such deposits were made in temporary lakes, accumulated between the ice on the one hand and a terminal moraine or higher land on the other. Many such temporary lakes accompanied the recession of the ice sheet, and have left small lacustrine plains to mark their former existence. Lacustrine plains of much greater extent, but due to the same causes, lie in the basins of the Great Lakes, and are traversed by the train in western Ohio and in the neighborhood of Chicago.

The moraine, first fully and accurately described in America, and which received the designation "kettle moraine,"[25] delimits a phase of the great ice sheet in which its margin was divided into lobes, each one a large glacier. Between Newark and Kilbourn City the route crosses the area overspread by the Scioto, the Maumee, the Saginaw Bay, the Lake Michigan, and the Green Bay lobes.

At Kilbourn City, Wis., the line of travel leaves glaciated territory and enters the driftless area[26] of the Upper Mississippi Basin. Thence to La Crosse the topography and the constitution of the surface material stand in sharp contrast to the corresponding features of the region farther east. Rock exposures, which have been rare eastward, and altogether wanting over considerable areas, are here of almost constant occurrence wherever the surface has any considerable relief. Frequently, too, butte-like hills or fantastically carved, castellated towers of sandstone give some indications of the extent of the subaerial erosion the region has suffered. From the presence of these bold eminences within the driftless area, rising 200 or 300 feet above the more or less completely base-leveled plain on which they rest, and from their absence in the area covered by ice, instructive inferences may be drawn as to the work effected by the ice in the country over which it passed. Before La Crosse is reached, the bluffs in the immediate vicinity of the Mississippi are capped with a thin sheet of loess, but this does not attain great thickness east of the Mississippi river in this latitude.

FROM THE OHIO RIVER TO CHICAGO.

ITINERARY.

By EDWARD ORTON.

Station.	Distance.		Elevation.		Population.	Stations.	Distance.		Elevation.		Population.
	Miles.	Kilometers.	Feet.	Meters.			Miles.	Kilometers.	Feet.	Meters.	
Bellaire	0	0	635	194	9,934	St. Joe	304	489	815	248	....
Barnesville	24	39	1,276	389	....	Auburn Junction	314	505	874	266	....
Cambridge	49	79	842	257	....	Garrett	317	510	891	272	....
Zanesville	75	121	742	226	21,009	Avilla	322	518	961	293	....
Newark	101	163	868	265	14,270	Albion	332	534	926	282	....
Mount Vernon	126	203	991	302	....	Cromwell	342	550	937	286	....
Mansfield	163	262	1,154	352	13,473	Syracuse	350	563	869	265	....
Chicago Junction	189	304	930	283	....	Milford Junction	355	571	842	257	....
Tiffin	213	343	758	230	10,801	Bremen	371	597	820	250	....
Fostoria	226	364	777	237	....	La Paz Junction	379	610	857	261	....
Bloomdale	233	375	755	231	....	Walkerton Junction	388	624	718	219	....
Welker	238	383	......	......	....	Wellsboro	403	649	753	230	....
North Baltimore	239	385	740	226	....	Allda	410	660	......	......	....
Deshler	251	404	720	219	....	Suman	416	669	746	227	....
Holgate	264	424	721	220	....	Willow Creek	426	686	......	......	....
Defiance	277	446	711	217	....	South Chicago	428	690	589	180	....
Sherwood	284	457	......	......	....	Chicago	460	740	589	180	1,099,850
Hicksville	297	478	761	232	....						

From **Bellaire**[19,20] for about 35 miles (55 km.) northwestward, the road traverses the northern edge of the great Pittsburg coal basin, the beds of which are rising to the northwest, 10 to 15 feet to the mile (2 to 3 m. to the km.). The coal seam has deteriorated in quality as it has been followed westward into Ohio. It still has good thickness (6 feet) and it preserves the coking quality which gives to it such great value in the Connellsville district of western Pennsylvania, but the percentage of sulphur has been so greatly increased that it no longer furnishes an iron-making fuel and for the same reason it is not acceptable as a gas-making coal. The seam lies 100 feet (30 m.) above the river near **Bellaire.** The geological section furnished by the river hills at this point covers the entire Upper Productive Coal Measures and reaches well up into the Upper Barren Measures. At no point in Ohio is there a better exposed natural section of this part of the geological column.

There are many horizons of limestone in these two divisions of the Coal Measures. The limestones are of fresh-water origin in the main, are readily soluble in atmospheric waters, and give rise by their decay to soils of unusual fertility. It thus happens that the hills of this portion of the State rank as high in agricultural wealth as the plains and valleys of the western half of the State. Some of the limestones of this series yield natural hydraulic cements of fair quality.

In the vicinity of **Barnesville**[21,22] the highest rocks of the Ohio scale are found. They have been proved by Fontaine and White, by means of their flora,[24] to have a Permian aspect, but having much in common with the underlying division they are generally recognized as a transition series under the name Permo-Carboniferous.

At **Cambridge** the railroad reaches the uppermost seam of the Lower Coal Measures of the State, the Upper Freeport Seam. A coal field of great importance begins at this point and extends for many miles to the southward and southeastward. Within the limits of this field the deepest-lying coal of the State is likely to be found. The seam has been followed by the drill to a depth of at least 500 feet (152 m.) below the valley levels to the southeastward. This coal has an excellent reputation as a steam coal. It has a maximum thickness of 7 feet, but, more than any other Ohio coal, it is liable to disastrous "wants" or "cutouts," due to its invasion by the great Mahoning sandstone, which is the next higher element in the normal section. A low anticline traverses the series near **Cambridge** which has proved effective in the accumulation of gas and oil to a small extent. The reservoir rock is the Berea grit, which here lies about 1,000 feet (304 m.) below the surface. A very important oil field is found at Macksburg, 30 miles (48 km.) south of **Cambridge**.

At **Zanesville** [17,20,21] two of the most important coal seams of the lower measures, the Lower and Middle Kittanning seams, are extensively mined. They underlie much of the town and are well developed in the surrounding country. A score of miles to the southwestward they constitute the Hocking Valley coal field which is now producing 5,000,000 tons annually and which is decdedly the most important coal field of the State.

Fire clays and shales are found associated with the coal seams in large amounts. They are proving far more valuable than the coals themselves, constituting as they do an excellent basis for the manufacture of building brick of all qualities, of paving brick (vitrified), of earthenware, and finally of encaustic tiles of the finest quality. The American Tile Works established here are the largest of their kind in the world, employing a thousand men and furnishing a product that competes successfully in the New York markets with the best grades of imported floor and ornamental tiles. **Zanesville** is the most important

clay manufacturing center in the State in the several lines above noted.

To the west of **Zanesville** and extending to the north and west as far as **Chicago Junction**[21] the Sub-Carboniferous series, consisting of conglomerates, sandstones, and shales, and containing an abundant fauna, admitting of several distinct subdivisions, occupy the country traversed by the railroad. The conglomerate portion of the series has been cut through by the Licking River between **Zanesville** and **Newark** and is well exposed in the picturesque gorge traversed by the railroad between these two points.

Near **Newark** the great terminal moraine[20] which marks the southern extension of the Drift is crossed and the drift-covered area is entered.

The sections exposed between **Newark** and **Chicago Junction** agree with those last named, but the rocks appear at comparatively few points.

At **Chicago Junction** the basal rocks beneath the drift belong to the black shale division of the Devonian. The drift beds are here 100 or more feet in thickness.

Near **Tiffin**[17,21] the first exposures of underlying Devonian and Silurian limestones are met with. They are found mainly in the valleys from which the mantle of the drift has been removed by erosion. Here begins the low anticlinal arch upon which the great accumulation of gas and petroleum in northwestern Ohio has been proved to depend. The central portion or summit of the arch is crossed between **Fostoria**[21] and **North Baltimore.**[22] Its structure is shown in the accompanying diagrammatic sections, (Figs. 8–10) the extremes of which are about 30 miles (48 km.) apart on the approximately north and south line of the axis of the arch.

The surface rock of the gas-producing portions of the arch is Niagara (Wenlock) limestone; of the oil-producing portions, the surface rocks are mainly Lower Helderberg (Ludlow) limestones.

The oil and gas districts are flat-lying regions, the extremes of the surface elevations of several hundred square miles not exceeding 50 feet (15 m.). The general level may be taken as 750 feet (225 m.) above tide. The reservoir of gas and oil lies 1,000 to 1,300 feet (300 to 400 m.) below the surface. At **Fostoria** and again at a point 6 miles beyond **North Baltimore,** the surface of the oil-bearing rock is nearly 500 feet (150 m.) below tide level. At **Bloomdale,** on the axis of the arch, it is 300 feet (90 m.) below tide. The measurements afforded by the drill indicate a gentle arch in the producing bed; when it is reached at 500 feet or more below tide, it is found charged with salt water. From 400 to 450 feet below tide, it carries oil; at higher levels gas is found.

The gas from this, and other adjacent and altogether similar fields in Ohio and Indiana, is transported by pipe lines to Toledo, Tiffin, Sandusky, Detroit, Fort Wayne, Indianapolis and scores of smaller towns,

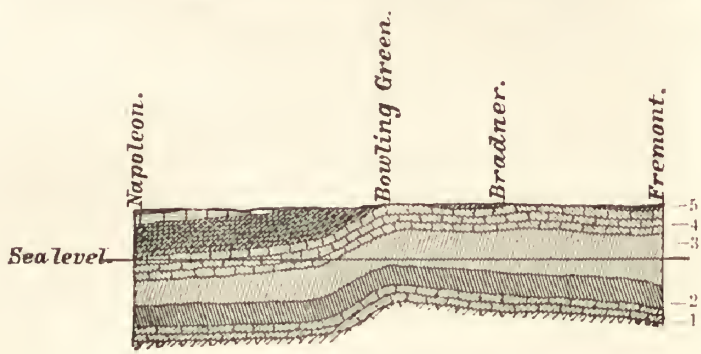


Fig. 8.

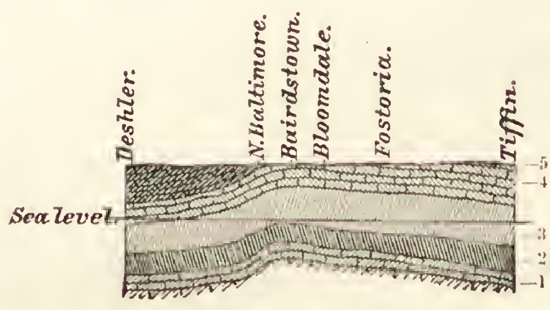


Fig. 9.

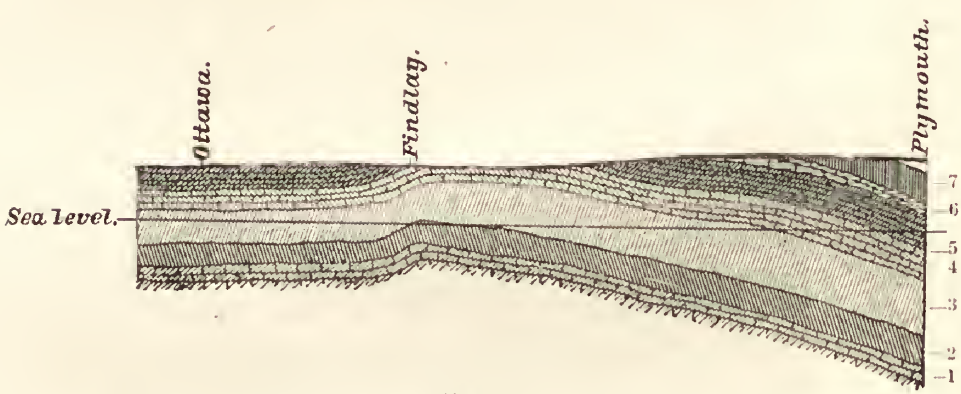


Fig. 10.

Sections across the oil field of Northwestern Ohio. (U. S. G. Survey. 8th Ann. Rep., p. 604.)

7. Ohio shale.
6. Upper Helderberg limestone.
5. Lower Helderberg limestone (Ludlow).
4. Niagara { limestone. shale. } Clinton limestone (Wenlock).
3. { Hudson River shale. Medina shale.
2. Utica shale.
1. Trenton limestone (Bala).

where it is used on a very large scale for manufacturing purposes and especially for domestic fuel. It is sold to the consumer for the latter

use at rates ranging from 5 to 25 cents per thousand cubic feet. It renders its most valuable service in the last-named capacity, introducing into the house the same convenience in heating and cooking that artificial gas does in lighting. The fire is always "laid," is kindled by a match, is regulated to any required point below its maximum by a cock, brings no soot or dust, and in short is the perfection of fuel. It is obviously the standard to which the fuel of the future will be obliged to conform. To this must be added that in the great majority of the favored towns, which it supplies, it is sold at a lower price than the coal which it displaces.

It brings equal advantage to the various lines of manufactures to which it is applied. In glass making, particularly, it introduces such economy and such improvement of product, that, other things being equal, competition with manufacturers that command it is very difficult on the part of those who depend on bituminous coal for fuel. It is a reproach to the intelligence of the communities that have obtained access to large supplies of gas to be obliged to add that, for several years after its discovery, it was generally furnished free to manufacturers and without measurement of any sort. This policy was entered upon in order to induce manufacturers to locate their plants in these towns. A single town has brought in establishments of this sort, mainly glass houses, enough to lead to the consumption of 30,000,000 cubic feet per diem (800,000 cu. m.) for the last three years.

But no gas field is able to bear such a strain as this amount of use brings; consequently there has been a rapid decline in the production of the wells, and it is now evident to all that the end of the large production is not far off. Five to eight years prove the limit for all sections that have found gas in large quantity and that have used it in the wanton way above described. The decline is most clearly revealed by the fall of pressure in the wells. The original pressure, due to the salt water contained in the same porous rock that holds the gas and oil, and falling under the laws of artesian wells, ranged from 400 to 500 pounds to the square inch (27 to 30 atmospheres).

Petroleum is also produced in large amounts from territory adjacent to the gas fields. The daily yield of the entire territory is between 40,000 and 50,000 barrels (of 42 gallons, or 158 liters each). The finest of illuminating and lubricating oils are made from the crude oil, and it also yields an unusually large percentage of paraffin. Both gas and oil contain a considerable percentage of sulphuretted hydrogen and probably other compounds of sulphur, and are consequently offensive in their natural state; but complete success has been attained in the deodorizing of the oil by several processes. Single wells, 5⅝ inches (13 cm.) in diameter, have produced oil at as high a rate as 8,000 barrels

per diem, when first drilled. One well recently finished is even said to rival the great fountains of Baku.

Bloomdale. This village is in the center of the original dry gas territory. The gas rock is struck at 1,065 feet (320 m.) below the surface, or 310 feet (93 m.) below tide. The wells in this immediate neighborhood yielded, when the field was fresh, between 3,000,000 and 4,000,000 cubic feet (80,000 to 100,000 cu. m.) per diem. The original pressure was 440 pounds to the square inch (29.3 atmospheres). The largest gas wells of the field have produced not less than 30,000,000 cubic feet (800,000 m.) in twenty-four hours, but such flows are short lived. Wells of this character are invariably overtaken by oil or salt water within a few days or weeks, if allowed to flow unrestrained.

North Baltimore.[21,22] On the east side of the town dry gas was originally found, but on the west side a great oil field has recently been developed. Hundreds of derricks can be seen from the cars. In the oil wells the Trenton limestone is struck at 1,190 feet (360 m.) below the surface, or 450 feet (145 m.) below tide. Three miles further west, the Trenton limestone sinks to 500 feet (150 m.) and more below tide and salt water occupies it everywhere, except in narrow ridges that are sometimes found in which a little gas or oil is contained.

These towns of the oil region all stand upon lacustrine deposits belonging to the period of the melting of the great ice sheet (Champlain). When the ice front occupied a position in the basin of Lake Erie a large body of water was held between it and the uplands to the south and west. At first this lake found outlet westward to Fort Wayne, Ind., but afterwards as the ice retreated further, other avenues of escape were opened and the water level fell, recording its position at different horizons by beaches. A beach line is crossed at **Fostoria** and another near **Defiance**, and still another near **Hicksville**. These old beaches, composed as they are largely of sand and limestone gravel, give rise to light and warm soils and sometimes to soils of extreme fertility.

Defiance.[18,21] The Devonian black shale is found on the western slope of the arch at this point, though generally concealed under heavy beds of boulder clay. The eastern outcrops of the shale were left at **Chicago Junction.** The drift beds seldom fall below 100 feet (30 m.) in thickness in this portion of the State, except in the river valleys, and they often rise to 200 and 300 feet (60 and 90 m.) in thickness. One section to the southward showed 530 feet (160 m.) of drift without reaching bottom.

Between **Hicksville,** Ohio, and **St. Joe,** Ind.,[23] a narrow moraine line is crossed.

At **Concord** is a morainic line, perhaps to be regarded as a part of that just east of **St. Joe,** separated from it by the valley of the St. Josephs River.

At **Auburn** the drill has revealed the presence of a slight fold in the deep-lying Trenton limestone, sufficient for the accumulation of gas and oil to a small extent. Despite the monotonous aspect of the present drift-covered surface, the underlying rocks have recently been found to be more broken by small folds and fractures than any other parts of the two states included in this review. Four or more wells, more than 2,000 feet (610 m.) in depth, have been drilled within the limits of **Auburn**. The gas found in the productive rock has a very high initial pressure. The first flow of the best wells showed more than 1,000,000 cubic feet per diem as the daily yield. The gas has been utilized in the town to the full extent.

The drift beds exceed 200 feet (60 m.) in thickness here. The first rock stratum reached beneath the drift is the basal portion of the black Ohio shale (Devonian). In the Lower Helderberg limestone (Upper Silurian), which has a thickness of about 600 feet (183 m.), considerable deposits of gypsum and anhydrite are found about midway in the series. At or about this same point in this series very important beds of rock salt are found in Ohio, Michigan, and Canada. These deposits are now being worked on a large scale in all three places. A valuable deposit of gypsum occurs in the same horizon in Ohio.

From **Auburn** to **Garrett** the basal rock is the black shale previously reported. The drift is nonmorainic.

At **Garrett** and just west of Garrett one line of the terminal moraine is crossed.

At **Albion** another belt of the terminal moraine is crossed. The region about **Albion** illustrates well the lack of drainage which is common along the terminal moraine. Numerous shallow lakes, ponds, and swamps are found here. A single lake will sometimes occupy several square miles of the surface.

Between **Teegarden** and **Walkerton** the line traverses the terminal moraine, the black slate of the Devonian still underlying the drift.

From **Walkerton** to **Coburg** is modified drift underlain by the Devonian to **Union Mills**, and by the Niagara limestone (Upper Silurian, Wenlock) from **Union Mills** to **Coburg**.

At **Suman** an inner morainic line of the Lake Michigan glacier is crossed. The morainic belt extends westward as far as **Woodville**.

From **Woodville** to **Chicago** the underlying rock is Niagara limestone, buried beneath modified drift, deposited in Lake Michigan during its expanded condition, in late glacial and postglacial times. Through a part of this region the sands of old beaches have been extensively modified by the action of the winds, forming in places conspicuous dunes. The road follows the southern and southwestern margin of Lake Michigan during the last 25 miles (40 km.).

The Niagara limestone which has been repeatedly named in the pre-

ceding account is extensively quarried at several points near Chicago. It is the Guelph division of the Niagara which is found here. In composition it is a typical dolomite of great purity. It was originally a highly fossiliferous limestone, and many species new to science have been described from the internal casts of the several divisions of the Mollusca that occur here.

South Chicago, a few miles beyond the Illinois State line and 11 from the Central Station, is already within the city limits. The road now bends to the westward, a mile or more away from the lake, to **Parkside**, and then runs north along the west side of Jackson Park, which occupies a mile and a half of the immediate shore line, and is the site of the Columbian Exposition. Beyond Jackson Park it again reaches the shore, which it follows for 6 miles to the Baltimore and Ohio station situated on the borders of Lake Park, which occupies a mile of the lake front opposite the central business portion of Chicago.

FROM CHICAGO TO THE MISSISSIPPI RIVER.

ITINERARY.

By S. F. Emmons.*

Station.	Distance.		Elevation.		Station.	Distance.		Elevation.	
	Miles.	Kilometers.	Feet.	Meters.		Miles.	Kilometers.	Feet.	Metres.
Chicago	0	0	589	180	Portage City	188	303	813	248
Western Union Junction	62	100	......	.....	Kilbourn City	205	330	897	273
Milwaukee *a*	85	137	583	178	New Lisbon	221	356	894	272
Brookfield	109	175	......	....	Tomah	240	386	966	294
Pewaukee	115	185	......	.....	Sparta	257	414	798	243
Oconomowoc	128	206	......	.....	La Crosse *b*	283	455	657	200

a Population, 204,468. *b* Population, 25

Chicago is the second city in size and in commercial importance in the United States, and probably the greatest railroad center in the world. Its population in 1890 numbered about 1,100,000 souls, an increase of 118 per cent over that given by the census of 1880. Its streets are laid out on the rectangular system adopted by all modern American cities. The first eleven east and west streets from the Chicago River southward have names (Lake, Randolph, Washington, Madison, Monroe, Adams, Jackson, Van Buren, Harrison, Polk, and Taylor streets);

* Geological data furnished by Prof. T. C. Chamberlin and Prof. R. D. Salisbury.

beyond they are numbered from Twelfth upward to Ninety-fifth street, which runs through South Chicago. The area covered by the named streets and by the nine principal north and south streets or avenues, next westward from Lake Park, comprises the principal business portion of the city, in which are its most imposing buildings. It is inclosed on the north and west by the so-called Chicago River, an inlet of the lake, which has been artificially deepened and connected with the Illinois and Michigan Canal. This runs southwestward into the Illinois River, so that the overflow of Lake Michigan through it reaches the Mississippi River. The site of this portion of the city was originally only about 7 feet above the lake level, but was artificially raised in 1885 to 14 feet.

The great fire of 1871, which started among wooden buildings in the western portion of the city under the influence of a strong southwest wind, destroyed nearly every building over an area of 2,124 acres (858 hectares), in less than twenty-four hours. This area included a great part of the massive buildings of stone and brick in the business center of the city, so that it is estimated that the value of the buildings alone that were destroyed was $53,000,000, while the total loss was $196,000,000. It was rapidly rebuilt, and the enormous blocks which have risen over the burnt district are among the finest specimens of commercial architecture in the country.

Chicago's water supply is mainly obtained from Lake Michigan, though artesian water is also used. Lake Michigan water is pumped through two tunnels 66 feet below the shore level and extending 2 miles out into the lake, where they connect with a vertical iron cylinder 64 feet (19 m.) high, inclosed in a crib of iron and wood loaded with stone. The water capacity of these tunnels is 150,000,000 gallons (550,000,000 liters) per 24 hours.

Chicago has spread rapidly, especially in the last decade, out onto the surrounding prairies, where enormous manufacturing and commercial establishments form small cities within themselves. Such are the great Union stock yards, the Pullman works, etc. It has also provided liberal breathing space for its rapidly-growing population in an elaborate system of parks. Six of these cover from 180 up to 590 acres (44 to 240 hectares) each, besides which are numerous open squares and smaller parks within the older portions of the city.

From **Chicago** to **Milwaukee** the route lies parallel to the shore of Lake Michigan, and within the area of lacustrine deposition of the Champlain epoch, when the boundaries of lake Michigan were much extended. Along this line the Champlain deposits reach westward 8 to 12 miles (13 to 19 km.) from the lake. The deposits immediately along the line of the railway are the "gray pebble clays" of the Wisconsin geological survey. The whole of this region is underlain by Niagara limestone.

At **Milwaukee** the surface formation is the gray pebble clay of Champlain age. Within the limits of the city Devonian (Hamilton) strata occur. This is the only area of Devonian rock within the boundaries of Wisconsin. The rock is an impure limestone, from which an excellent hydraulic cement is made. The Niagara limestone, upon and against which the Devonian lies, is here of such a character as to afford an excellent building stone, and is extensively quarried for that purpose.

At **Wauwatosa**, also, there are extensive quarries in the Niagara limestone, similar to those in Milwaukee. The gray pebble clay, of Champlain age, extends somewhat west of Wauwatosa.

From **Wauwatosa** to **Pewaukee** till (ground moraine) is well shown, underlain by Niagara limestone.

Pewaukee to **Oconomowoc.** About midway between these two stations (from Hartland to Nashotah) the Kettle moraine is crossed,[25] and here its characteristic topography, its accompaniment of lakes and its constitution, may be seen. Between these stations also the Hudson River shale appears from beneath the Niagara limestone, but is concealed by the drift. The Niagara limestone dips to the eastward, and the Hudson River shale is the next subjacent formation and appears at the surface, except for the drift covering, as the Niagara thins out to the westward. Before **Oconomowoc** is reached, the Galena (Lower Silurian) limestone appears from beneath the Hudson River shale, as the Hudson River shale appeared from beneath the Niagara. The region about **Oconomowoc** is famous for its lakes. The moraine crossed between **Pewaukee** and **Oconomowoc** is the joint product of the Lake Michigan and Green Bay glaciers, the ice from the Lake Michigan glacier moving westward and the ice from the Green Bay glacier moving eastward. The two ice movements met along the line of this moraine, which is therefore an interlobate moraine, terminal to two ice movements in opposite directions.

Between **Oconomowoc** and **Columbus** the ground moraine finds one of its typical phases of development. Particularly in the region about Watertown, and northwestward from Watertown to Columbus, drumlins are well developed. The drumlins have here a northeast-southwest trend. This corresponds to the direction of ice movement in this region, as shown by the striæ. Associated with the drumlins are undrained or ill-drained depressions which have an extension in the same direction as the drumlins themselves. Between **Watertown** and **Columbus** the underlying strata are the Trenton (Lower Silurian) limestone, the St. Peter's sandstone, and the Lower Magnesian limestone, in the order named. The strata all dip slightly to the southeastward, and each formation appears from beneath the one preceding.

From **Columbus** to **Rio** is ground moraine, underlain by Lower Magnesian limestone, and from **Rio** to **Portage**, drift, underlain by Potsdam (Cambrian) sandstone. At **Portage** the Wisconsin River is reached, and it is followed to **Kilbourn City**, through Potsdam sandstone, overlain by drift. Just before **Kilbourn City** is reached the moraine formed at the western margin of the Green Bay glacier is crossed. At **Kilbourn City** the railway crosses the river at about the center of that portion of its valley known as the Dalles of the Wisconsin. The river here flows through a canyon-like gorge, 50 or 60 feet deep, carved out of the Potsdam sandstone. The tributaries to the Wisconsin in this part of its course have cut for themselves deep gorges and glens leading down to the main stream. From the railway line near **Kilbourn City** may be seen isolated elevations of Potsdam sandstone, which represent erosion remnants of the once more extensive Potsdam formation.

Kilbourn City to Camp Douglas. Crossing the river at **Kilbourn City**, the driftless area[26] is entered. The sharp erosion forms, the absence of drift topography, and the frequency of rock exposures combine to place this region in sharp contrast to that farther east. In the vicinity of **Mauston, New Lisbon**, and **Camp Douglas** fine castellated outliers of Potsdam Sandstone may be seen resting on a lower and often nearly level plain of the same formation.

Camp Douglas to Sparta. Between these stations the Potsdam sandstone is the only formation which appears. The divide between the Wisconsin and the Mississippi is here crossed, and from the summit the topography of the driftless area may be well seen.

From **Sparta** to **La Crosse** the route lies in the valley of the La Crosse river. The valley is carved from the Potsdam sandstone, which forms the bluffs on either hand. In the lower part of the valley the summits of the bluffs are capped with lower Magnesian limestone. Loess also occurs on the summits of the bluffs fronting the Mississippi, and on the bluffs bounding the La Crosse valley, near its junction with the Mississippi.

THE STATE OF MINNESOTA.

By Uly S. Grant.*

Topography.—The topographic features of Minnesota may be briefly summed up, for its western three-quarters, as being a moderately undulating, sometimes nearly flat, and occasionally hilly expanse. The only exceptions to this topographic character are the northeastern and southeastern corners of the State, the former being almost mountainous, and the latter deeply eroded valleys, often destitute of drift. The northwestern corner is a part of the valley of the Red River of the North, and is extremely flat and monotonous. It is made up superficially of deposits from the glacial lake, Agassiz, and well represents an area which is topographically young, the river courses having but just begun to cut shallow narrow channels in the unconsolidated materials. The extreme northeastern part of the State has little drift, and is very rough and broken in outline, the rugged summits of hills of crystalline rocks giving many bold features to the landscape. In the southeastern corner the Mississippi river and its tributaries are inclosed by bluffs from 200 to 600 feet (61 to 183 m.) in height; these bluffs consist of nearly horizontal Paleozoic rocks.

The average elevation of the State is somewhat over 1,200 feet (366 m.) above sea level. The only part that can be termed at all mountainous is the district between Lake Superior and the Canadian boundary. Here three parallel ranges of hills trend northeastwardly, and rise in some places to an altitude of 2,200 feet (671 m.). The most broken country is that immediately bordering on Lake Superior, where, in from 2 to 10 miles (3 to 16 km.) back from the shore, the land rises over 1,000 feet (305 m.). The region around the sources of the Mississippi has an altitude of 1,700 feet (518 m.), and in the northwest-central part of the State a gentle range of hills (the Leaf hills) rises to a height of 1,750 feet (533 m.). The Coteau des Prairies, an elevated region in the southwestern portion of Minnesota, is from 1,800 to 1,900 feet (549 to 579 m.) above sea level.

Lakes and rivers.—The water area of Minnesota is larger than that of any other State of the Union, being 5,637 square miles,† or nearly one-fifteenth of the whole area of the State. The total number of lakes

*Compiled largely from the reports of the Geological and Natural History Survey of Minnesota.

†This estimate does not include any part of Lake Superior

is about ten thousand, and they are scattered over nearly the entire surface of the State, but the larger proportion are confined to the morainic areas. These lakes are of all sizes, from small ponds to bodies of water 12 miles (19 km.) or more in diameter. Their shores are mostly of drift, and rarely does the underlying rock appear anywhere in their basins. This is not true of those lakes in the district between Lake Superior and the Canadian boundary, which are for the most part rock bound.

There are three drainage systems. The most important is that whose waters find their way into the Gulf of Mexico through the Mississippi, whose largest tributary in the State is the Minnesota river. This basin includes fully two-thirds of the area of the State; the whole of the southern half, the northern-central and the central-eastern part of the State belong to it. The next largest is the Hudson Bay system, including the Red River of the North, which drains the northwestern portion, and the Rainy river which drains a small strip along the northern edge of the State. The third system is that of the Gulf of St. Lawrence; this is by far the smallest of the three systems and includes only the streams in the immediate neighborhood of Lake Superior.

Flora.[27]—The most important and conspicuous contrast presented by the vegetation covering different parts of Minnesota is its division into forest and prairie. Forest covers the northeastern two-thirds of the State approximately, while about one third, lying at the south and southwest and reaching in the Red River valley to the international boundary, is prairie. The line dividing these areas has an almost wholly timbered region on its northeastern side and on its southwestern side a region that is chiefly grass land, without trees or shrubs excepting in narrow belts along the larger streams and occasionally groves beside lakes. In the northern half of the State the timber consists largely of conifers, from which large amounts of lumber are annually taken. The deciduous forest exists for the greater part in the southern half of the State, and is composed chiefly of various species of oak, elm, linden, poplar, maple, and ash.

The geological column.—In the State of Minnesota there are to be seen rocks from the fundamental complex of gneiss and schist (Archean) up to those which are being formed at the present day. There are, however, several wide breaks in the geological column where formations of great importance are entirely lacking. In the Paleozoic, Carboniferous and Permian are without representatives. In the Mesozoic, the Triassic and Jurassic are completely wanting, the only Mesozoic rocks that are known being a few isolated areas of Cretaceous strata, very limited in extent. The Tertiary is also entirely lacking.

Below is given a brief account of those formations found within the limits of the State.

Group.	System.	Series.
Cenozoic	Pleistocene	Recent Glacial.
Mesozoic	Cretaceous	
Paleozoic	Devonian	Corniferous.
	Silurian	Hudson River. Galena. Trenton.
	Cambrian (Ozark series)	St. Peter. Shakopee. Richmond. Lower Magnesian. Jordan. St. Lawrence. St. Croix.
Algonkian (Taconic)	Keweenawan (Nipigon)	
	Huronian	Animikie.
Archean	Laurentian?	Keewatin. Vermilion. Gneiss, etc.

The Archean is made up of semicrystalline and crystalline schists, gneisses and granites, and basic eruptives. The semicrystalline schists are mostly sericitic and argillaceous in character and, together with a large number of graywackes and greenstone schists, compose the Keewatin series. In this series are found extensive beds of very pure hematite, which supply an excellent ore for steel-making.[28] The crystalline schists are micaceous and hornblendic and lie below the less crystalline; they belong to the Vermilion series, as described in the reports of the Minnesota survey. Still lower are gneisses and granite. The entire Archean has been broken through by ancient eruptives, mostly granites and quartz-porphyries, and by more recent diabases. The Archean has its greatest development in the region along the international boundary north and east of Vermilion Lake. Here the strata strike in a general east-northeast direction, and the dip varies only a few degrees from the vertical.

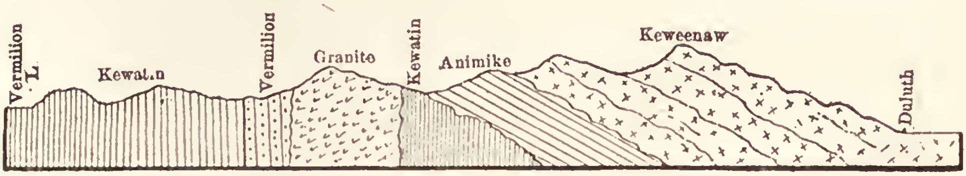


FIG. 11.—General section from Vermilion lake to Duluth.

This formation extends southwestwardly through the State, outcrops being occasionally seen, especially in the upper Minnesota val-

ley, where, however, the three divisions described above are not recognizable. But, as a rule, west and southwest from Duluth these rocks are hidden by the drift.

The Algonkian (or Taconic of the Minnesota survey) is seen in its greatest development in the country lying just north of Lake Superior. It is separated into an upper and lower division—the Huronian and Keweenawan.

The Huronian in Minnesota is represented by dark carbonaceous slates and ferruginous quartzites. A belt of these rocks stretches from the extreme eastern end of the State west and southwest to the vicinity of Duluth and to the Mississippi river. They lie just south of the Archean complex and rest on its upturned edges. The dip is at low angles toward Lake Superior. After going a few miles northwest of Duluth the Huronian is seldom seen until reaching Pokegama Falls on the Upper Mississippi, and west of this these rocks are completely covered by glacial deposits. The Huronian in Minnesota is included under what has been described as the Animikie on the north side of Lake Superior.

The Keweenawan consists chiefly of interbedded sheets of intermediate and basic eruptives, with a few clastics. These rocks occupy the territory south of the strike of the Huronian and north of Lake Superior. They are seen in great development in the vicinity of Duluth and all along the lake shore to Pigeon Point.[29] The principal rock type is a very coarse-grained, gray gabbro, which has a geographical extent of 1,000 square miles (260,000 hectares). It is used somewhat for a building stone, and is well known as "the Duluth granite."

The Paleozoic.—To this belong the rocks of the entire southeastern and southern portions of the State. They are comparatively little exposed, except along the river courses.

The Cambrian extends along the Mississippi river and its tributaries from St. Paul to the southern limit of the State. It is especially well exposed in the bluffs along the Mississippi. The eastern part of the State, north of St. Paul and south of Duluth, is also occupied largely by Cambrian strata. A belt also extends from the last area southwestward along the southern border of the Archean to the extreme southwestern corner of the State. The rocks of this formation are mostly thick beds of magnesian limestone and of sandstone, but in the area lying in the southwestern corner of Minnesota an extensive quartzite occurs; associated with this is the famous Indian "pipestone" or catlinite.

The Silurian is seen overlying conformably the Cambrian in many places along the Mississippi river. It is represented only by a comparatively small thickness of strata, which are confined almost entirely to the Lower Silurian. Its chief member, the Trenton limestone, is seen in its best development along the Mississippi in the vicinity of

St. Paul and Minneapolis. The Silurian underlies the drift (occasionally appearing through it) of a considerable area in the southeastern portion of the State just west of the Mississippi.

The Devonian occupies a small portion of territory along the central part of the southern border of Minnesota. It is chiefly represented by the Corniferous (and Hamilton?) limestones and is comparatively thin.

The Mesozoic.—The only Mesozoic strata found are small isolated areas of Cretaceous. These occur in basins in the older rocks and are exposed in a few places along river courses. The Cretaceous rocks contain many well-preserved fossil leaves, which have been described by Leo Lesquereux.[30]

The Cenozoic.—Nearly the whole of the State may be said to be drift-covered; the only exceptions are the extreme southeastern and the extreme northeastern portions. At any point on the northwestern boundary, as far east as Lake of the Woods, one may start southward and follow the Iowa boundary line without seeing any rocks *in situ*, except what he might encounter in crossing the valley of the Minnesota river, and the rare exposures of red quartzite in Rock, Pipestone and Cottonwood counties. East of this meridian he would encounter occasional exposures of such rocks along Rainy river, but southward from the northern boundary he would still have an almost equal scarcity of rock exposures, were he to set out again to the Iowa boundary line. The drift is so thick in the region of lakes Pemidgi and Winnibigoshish, and generally through the central portion of the State, that it does not afford rock exposures until reaching the vicinity of Motley. Rock is seen in scattered patches in Todd, Morrison, Mille Lacs, Kanabac, Stearns, Benton, and Sherburne counties, as well as at Pokegama Falls on the Upper Mississippi. But farther toward the south, except in the valleys of the Minnesota and Blue Earth rivers, the drift everywhere conceals the rock with an unbroken mantle from 100 to 200 feet, (30 to 60 m.) and sometimes 300 feet (91 m.) thick.

East of the meridian passing through the west end of Rainy Lake, the rock is more and more frequently seen projecting above the drift, both along the Iowa boundary and in the central and northern portions of the State, especially in the valleys of streams that flow eastward. There is a tract of the State heavily covered by drift east of Pokegama Falls, including the St. Louis Valley and its upper tributaries, in which many of the streams that enter Lake Superior in the State of Minnesota take their rise; but for the most part in the eastern half of the State the streams expose the rocks more and more frequently, indicating an attenuation of the drift sheet toward the east, so that at last they become continuously rock-bound. The drift fades out on the north toward the rock-bound shore of Lake Superior, as remarkably evinced along the international boundary, and on the

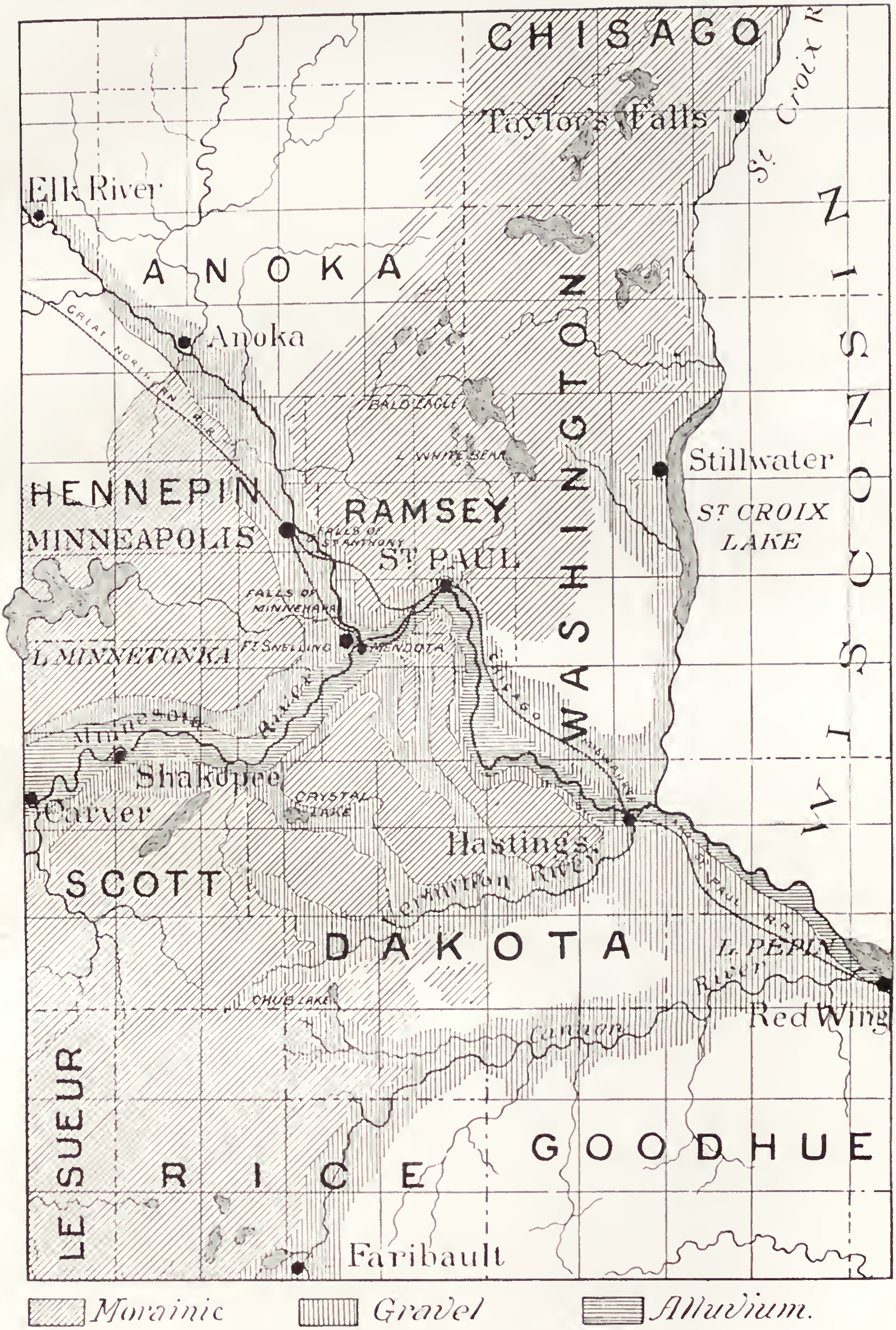
south toward the equally ancient rocky valley formed by the St. Croix and the Mississippi.

Morainic accumulations are very extensively developed throughout the State. The most prominent are those of the eastern border of the glacial lobe which extended into central Iowa. This series of moraines enters the State about the center of the eastern boundary, runs southwestwardly to the vicinity of St. Paul and Minneapolis, and then turns and runs southward to the southern limit of the State. The moraines of the western side of this lobe cut across the southwestern corner of the State. Between these two major terminal moraines are many complicated net-works of minor moraines, formed as this great lobe of the glacier receded northward.

The "driftless area" is the only portion of the State that is entirely free from drift. This area, although confined mostly to Wisconsin, covers a considerable territory in the southeastern corner of Minnesota. Most of Houston and Winona counties and the eastern portions of Wabasha, Olmsted and Fillmore counties are included in this area. Here the topography is decidedly more rugged than in the adjoining drift-covered areas, and the rocks are exposed in bold outcrops.[26, 31]

The loess is well developed in the southeastern corner of Minnesota. It covers all of the driftless area in the State and extends a short distance west of it, and also northward along the Mississippi nearly to Red Wing. Outside of the driftless area it is confined chiefly to the river valleys, extending along these much farther west than in the adjoining ground.

Lake Agassiz.[32]—This name has been applied by Mr. Warren Upham to a glacial lake which occupied the basin of the Red River of the North and extended over a considerable area in Manitoba. After the ice sheet had receded beyond the source of the Red River, the waters, formed from the melting of the ice, accumulated in a vast inland lake: the high ground to the south was the southern barrier of this lake, while on the north it was bounded by the edge of the retreating ice sheet. When the ice disappeared the present drainage system toward Hudson Bay was established. The area of this lake at the time of its greatest development was greater than that of Lake Superior. In depth it varied much, reaching in some places over 400 feet (123 m.). The beaches of Lake Agassiz are well defined in Minnesota; they enter the western edge of the State at Lake Traverse, run east for a short distance, and then north, keeping parallel with the Red River of the North and usually within 20 (32 km.) miles of it; this northerly direction continues to almost the latitude of Red lake, where it suddenly turns to the northeast and runs through Red lake to Rainy lake on the northern border of the State. The outlet of Lake Agassiz was the Minnesota River, which is now a small stream flowing in a gorge



GEOLOGICAL MAP OF VICINITY OF ST. PAUL AND MINNEAPOLIS.

that could only have been cut by a volume of water many times the size of the present river.*

The recession of the Falls of St. Anthony.[33,34]—This subject is of interest, as it furnishes data for the calculation of the time which has elapsed since the glacial period. The results practically agree with those obtained from Niagara Falls and elsewhere, and furnish strong evidence that the disappearance of the ice sheet from North America was less than ten thousand years ago.

From the Falls of St. Anthony to Fort Snelling (see map), a distance of a little over 8 miles (13 km.), the Mississippi flows in a deep gorge about 1,000 feet (305 m.) wide. The rocks of this region are covered by drift averaging, where the river has cut through it, probably not more than 30 feet (9 m.) in thickness. Immediately below the drift occur the practically horizontal beds of the Trenton, with a thickness of from 20 to 30 feet (6–9 m). The upper and lower beds are of comparatively soft shales, but the greater part is of hard compact limestone. The Trenton lies conformably on the St. Peter sandstone, which is a pure sandstone of uniformly fine grain and, notwithstanding its age, has undergone very little induration. This very friable sandstone is nearly worn away and allows large blocks of the limestone to fall down, thus materially increasing the rate of recession of the Falls.

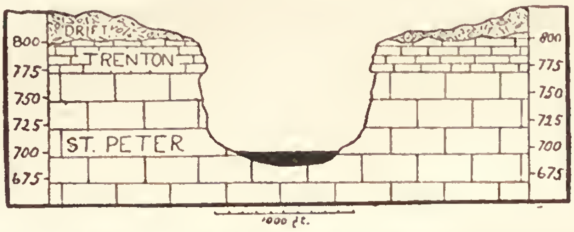


FIG. 12—Section across Mississippi River above Fort Snelling.

From the Falls to Fort Snelling the rock on the sides of the gorges has a freshly broken appearance, the large fragments thrown down by the action of the water on the easily crumbled sandrock, as the falls receded, still existing in the talus below the bluffs. Throughout this extent the strata are horizontal, the thickness of the drift sheet overlying them nearly uniform, and all other conditions, so far as they can be seen, that would affect the rate of recession, seem to have exerted an unvarying influence. The inference is that the rate of recession has been practically uniform between the two points named.

There is an aspect of age and long weathering presented by the rock in the bluffs of the Mississippi below Fort Snelling. It has a deeply changed color, a light yellow oxidized exterior, which marks all old

* Lake Agassiz is to be fully described by Mr. Warren Upham in a forthcoming monograph of the United States Geological Survey.

bluffs. This stained condition also pervades the rock at the mouth of Bassetts creek and at the quarries in the ancient river bluffs near the mouth of Shingle creek, on both sides of the river. (Both of these places are above the Falls.) Another notable difference between the bluffs above Fort Snelling and those below consists in the absence of caves and subterranean streams entering the river above Fort Snelling. Although the Trenton limestone exists in full force about St. Paul, in the bluffs east and north of the city, yet it has been cut through by some means prior to the drift so as to allow the entrance and exit of streams of water, at levels below its horizon, through the sandstone. None such are found above Fort Snelling, the surface drainage being shed by the limestone and precipitated over the brink of the gorge in several beautiful cascades. When such streams enter the river below Fort Snelling they either enter some subterranean passage and appear at the mouths of caverns in the sandstone, or as springs in the drift along the talus, or they find an ancient ravine down which they plunge by a series of rapids over boulders to the river level, rarely striking either the limestone or the underlying sandstone. Again, the rock

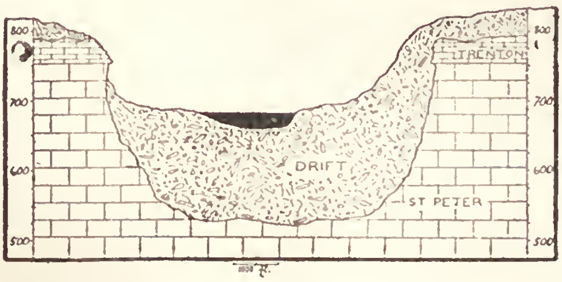


FIG. 13.—Section across the Mississippi River below Fort Snelling.

bluffs at St. Paul and everywhere below Fort Snelling are buried under the drift sheet. Their angles are sometimes seen jutting out from some wind-beaten corner, but nearly everywhere they are smoothed over by a mantle of drift and loam. Even the immediate river bank, where the lime rock should be intact, shows that it has been extensively disrupted, and its débris, often coarse and water-worn, in pieces from 4 to 10 feet long, is mixed with coarse boulders, gravel and drift at the height of 50 to 75 feet (15 to 23 m.) above the water level, the heterogeneous mass lying on the water-worn surface of the St. Peter sandstone.* But above Fort Snelling the upper edge of the limestone is intact all the way to the Falls and shows a fresh-cut section. It is surmounted by a continuous sheet of drift, which rises as a direct continuation of the bluff formed by the underlying rock. The individual strata of the drift show

*A good example of this is seen along the Chicago, Milwaukee and St. Paul Railroad tracks just west of the Union station at St. Paul.

that they were cut by the recession of the Falls in the same manner as the rock beds, and they do not conform in their undulations to the outline of the rock as if the gorge were present when they were formed, as in St. Paul. There is no spreading of loam over these cut edges, except what has fallen down from above at the time of their removal or subsequent to it. At Fort Snelling the direction of the Mississippi changes abruptly at a right angle, and the river enters the wider gorge in which the Minnesota flows, which gorge is entirely out of proportion with the amount of water that it carries. This gorge (of the Minnesota) continues in the same direction and with the same width beyond the confluence with the Mississippi, but takes the name of the latter stream; one mile below Fort Snelling this gorge is a mile and a half wide (2·4 km.).

These features of greater age, pertaining to the bluffs of the Mississippi below Fort Snelling, are seen in the old rock bluffs of the river above the mouth of Bassetts creek as far as Shingle creek. The rock there is deeply changed in color and is hid by the drift, and the bluffs, as left by the more ancient river, are far apart, the old gorge being three or four times as large as that between the Falls and Fort Snelling. These rock bluffs, consisting of the same limestone as that which at the Falls is below the water, here rise from 30 to 40 feet (9 to 12 m.) above the river and are buried under loam or drift and loam. This part of the old valley continues southwardly at first by way of Bassetts creek, across the western suburbs of Minneapolis, through the valleys occupied by lakes Calhoun and Harriet, and joins the Minnesota at some point above Fort Snelling, the precise locality being hid by a deposit of drift. It was cut down into the St. Peter sandstone over 100 feet (30 m.) at least, as shown by the well at the Sumner school house, and about 275 feet (84 m.), as shown by the deep well at the Lakewood cemetery. This would show that probably the ancient valley of the Minnesota, where it passes Fort Snelling, and all the way through Ramsey County and below, has been filled more than 200 feet (61 m.) by drift that originated since the excavation of the gorge. This supposition is borne out by all borings that have been made between the rock bluffs at lower points, as at West St. Paul and at Lake City on Lake Pepin. Such excavation is not found in the river gorge between Fort Snelling and the Falls of St. Anthony, the solid rock being found not more than 25 feet (7·8 m.) below the bottom of the water.

These facts warrant the conclusion that that part of the Mississippi gorge above Fort Snelling has been excavated by the recession of the Falls since the last general drift movement, and that prior to that event there was a gorge which passed from the present channel of the Mississippi, at the mouth of Bassetts creek, southward to the great gorge of

the Minnesota at some place above Fort Snelling. It is probable that this old channel of the Mississippi was then occupied by waters that drained the northern part of the State, and had existed through many ages, dating back to pre-Cretaceous times. It seems to have remained open to the advent of the ice of the last glacial period, when morainic accumulations so choked it that the water of the river was driven out and compelled to seek another passage to the Minnesota. When this last event took place the Falls of St. Anthony probably began at Fort Snelling, the water being precipitated over the rock bluff of the pre-existing old gorge, unless, as was very likely the case, the whole valley was too deeply buried under water. Whether this was at the beginning or at the acme of cold, or at the recession of the ice, is a question to be considered, but at this time the only point that is claimed is that it was not earlier than the beginning of the last glacial epoch, and was very probably near the close of this epoch, for the following reason. It has been before stated that the Minnesota was the outlet of the glacial lake Agassiz, and as such must have carried away enormous quantities of water resulting from the rapid melting of the ice sheet toward the north. There is good reason to believe that this swelled the river to such a height that the level of its waters rose as high as, if not higher than, the limestone ledge at Fort Snelling. If such was the case there could have been no fall at that place. When Lake Agassiz began to be drained to the north, the Minnesota's volume of water was much decreased and the water level fell below the limestone ledge. Then the waters of the Mississippi began to be precipitated over the face of this ledge, and then, and not until then, the recession of the Falls began. If this reasoning is correct, the date of the beginning of the recession of the Falls could not have been until near the close of the glacial epoch.

From calculations based on the recession from 1680 to 1856 Prof. Winchell obtained from three sources the rates of 4.79, 6.73, and 5.08 feet (1.46, 2.05, and 1.54 m.) per year, and the periods necessary for the recession of the Falls from Fort Snelling (a distance of a trifle over 8 miles) (13 km.) 8,819, 6,276 and 8,315 years. The average of these results is 7,803 years.

LA CROSSE TO MINNEAPOLIS.

ITINERARY.

By Uly S. Grant.

Station.	Distance. Miles.	Distance. Kilometres.	Elevation. Feet.	Elevation. Metres.	Population, 1890.
La Crosse	0	0	657	200	25,090
Dresbach	4	6	674	205	....
Dakota	6	10	655	200	....
Richmond	10	16	672	205	....
Lamoille	15	24	658	200	....
Homer	19	31	661	201	....
Winona	24	39	660	201	18,208
Minnesota City	30	48	675	206	....
Whitman	35	56	678	207	....
Minneiska	40	64	670	204	....
Weaver	43	69	672	205	....
Kellogg	51	82	701	214	....
Wabasha	57	92	711	217	2,487
Reads Landing	59	95	686	209	446
Kings Cooley	63	101	.....	.....	.....
Lake City	69	111	703	214	2,128
Frontenac	76	122	718	219	....
Wacouta	80	129	706	215	....
Red Wing	86	139	685	208	6,294
Eggleston	94	151	689	210	....
Etter	99	159	689	210	....
Hastings	107	171	707	215	3,705
Langdon	113	182	811	247	....
Newport	119	193	749	228	....
Daytons Bluff	126	203	707	215	....
St. Paul	127	204	703	214	133,156
Mendota	.....	.....	759	236	....
Fort Snelling	.....	.....	722	220	....
Minnehaha	.....	.....	813	247	....
Minneapolis	137	220	826	252	164,738

At **La Crosse** the Mississippi river is first seen. At the point of crossing of the railroad the low-water and high-water marks are respectively 628 feet (191·4 m.) and 643·5 feet (196·1 m.) above the sea level. The river varies much in width from here to Lake Pepin, sometimes being not more than half a mile (0·8 km.) across, and again spreading out to nearly three times that distance. The railroad follows the river almost continuously until reaching **St. Paul**, and along this route is the finest scenery in the whole Mississippi valley. The river is confined between high bluffs, precipitous in many places, and its flood plain is as a rule comparatively narrow.

From **La Crosse** to **Winona** the road follows close to the river's edge. The high bluffs on either side are of Cambrian strata; St. Croix sandstone capped by Lower Magnesian limestone. In some of the shaly layers of the St. Croix, near **Winona**, are found many shells of *Lingula*; in fact one bed of 16 inches (0·41 m.) in width is made up almost entirely of linguloid shells. The bluffs rise in many places precipitously from

the railroad, and their tops are often over 550 feet (168 m.) above the river and not more than a mile (1·6 km.) distant from it. Just before reaching **Winona** the valley widens, so that there are 2 to 3 miles of low level land between the bluffs and the water; this continues to about a mile (1·6 km.) north of **Minnesota City**, where the bluffs are again close to the river.

From **Minnesota City** to **Mount Vernon** this narrow valley continues. But beyond the latter point the bluffs rapidly recede from the river until they are 4 or 5 miles (6·4 to 8 km.) away from it. The railroad leaves the river proper and runs near the foot of the bluffs. The wide valley continues until reaching **Reads Landing** at the foot of Lake Pepin.

Lake Pepin is merely an expansion of the Mississippi. It is about 20 miles (32 km.) in length, and nowhere exceeds 3 miles (4·8 km.) in width. It is a most beautiful expanse of water, and many of the towns on its shores are summer resorts—as **Lake City**, Florence, and **Frontenac**.

At **Red Wing**, Barn Bluff (formerly known as La Grange mountain) is seen. It is a large butte of Cambrian rocks left within the river valley proper. Thus far the rock in the immediate vicinity of the railroad has been St. Croix sandstone, but before reaching **Hastings** the higher members of the Cambrian are entered.

At **Hastings** the river is crossed, and from this point to **St. Paul** the railroad keeps on the east side of the river, and usually at some distance from it. After crossing the river at **Hastings** the road runs through terrace gravel and sand, formed by washing of the drift material by the Mississippi, when it was flooded by the melting of the retreating ice sheet. Before coming to **St. Paul** several miles of recent river alluvium are crossed, and just before entering the Union railroad station at **St. Paul** the railroad skirts the base of a high precipitous bluff of St. Peter sandstone, which is capped by a bed of Lower Silurian (Trenton) limestone.

St. Paul and **Minneapolis**, the "twin cities" having an aggregate population of over 300,000, form an important business center. They stand on the highway between the great wheat producing fields of the Northwest and the markets of the East, and have tributary to them vast agricultural and lumber districts. The business centers of the two cities are about 10 miles (16 km.) apart, connected by half-hourly trains; the resident portions join. The cities are beautifully situated on the banks of the Mississippi, and abound in fine residences, pleasant drives, and picturesque little lakes. As an educational center **Minneapolis** and **St. Paul** are well in advance; within their limits are Hamlin University, under Methodist control; Macalaster College, under the charge of the Presbyterians; and the University of Minnesota, which is at the head of the State's system of public instruction and has 1,300 students.

St. Paul, the capital of Minnesota, is the older of the two cities, and is situated at the head of navigation on the Mississippi river. It forms an important commercial center and is well known throughout the Northwest on account of its wholesale trade. The western part of the city, called St. Anthony Hill, is the best resident district, and contains many beautiful homes, which overlook the river.

Minneapolis is best known for its lumber and flour interests. The new patent roller process of grinding wheat, together with the excellent quality of wheat of this region, have here built up the largest milling center in the world. The mills of the city have a daily capacity of over 44,000 barrels, and the Pillsbury "A" mill alone can produce 7,200 barrels of flour per day. The Falls of St. Anthony, famous as a great available water power, and Minnehaha falls are points of interest to the tourist.*

The geology of the vicinity of St. Paul has been partially explained in the preceding paragraph on the recession of the Falls of St. Anthony. Back from the river are large accumulations of drift materials in the form of moraines and intramorainic till. Along the river courses, at low altitudes, are small deposits of recent river alluvium, while higher up are larger and coarser deposits of modified drift, probably made by the rivers when flooded by glacial melting. Practically the same state of things exists around Minneapolis, with the exception of those peculiarities described in the pages treating of the recession of the Falls of St. Anthony.

From St. Paul to Minneapolis via Fort Snelling.—After leaving the Union Station at **St. Paul** the road passes along the foot of the bluff for some distance. Here the old, decayed and eroded condition of the St. Peter sandstone can easily be seen, together with some of its caves and subterranean water courses. In places, resting on this sandstone, are remarkable mixtures of soil, drift pebbles and boulders, and large angular fragments of Trenton limestone. These fragments are in all positions and are often over 20 feet (6 m.) long and 3 feet (0.9 m.) in thickness. It is probable that this composite mass was formed by the river when its level was much above the present level. Similar angular blocks of limestone, mingled with the glacial débris, can be seen in the bed of the Mississippi river above Fort Snelling; in fact, the whole river bed (above Fort Snelling) is more or less composed of such a mass of fragments which extend down to the solid rocks, 10 to 25 feet (3 to 7.6 m.) below the bottom of the river. After crossing the river the road runs along the southern bluff, of St. Peter sandstone capped by Trenton limestone, to **Mendota**.

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* Guide books to each city can be procured from book dealers. The best one to Minneapolis is Hudson's Dictionary to Minneapolis, 1891, published by the Beard-Hudson Printing Company, 10 North Fourth street.

From **Mendota** to **Fort Snelling** the broad valley of the Minnesota is crossed, and beyond the latter point the narrow gorge of the Mississippi is entered. At **Fort Snelling** one can easily see the difference between the broad ancient gorge of the Minnesota and the Mississippi and that of the Mississippi above this point.* The new narrow gorge is now followed for a short distance, but the railroad soon rises above it and reaches Minnehaha falls after passing through a few shallow cuts in the Trenton limestone.

Minnehaha falls at present show a small volume of water; this is due to the damming up of the headwaters of the stream in order to raise the level of lake Minnetonka. The height of the fall is 56 feet (17 m.) from the brink to the surface of the water in the pool below the fall. Below this the stream flows eastward in a narrow gorge for about 700 feet (213 m.), when it enters a much wider gorge, and in this continues to the river. This wider gorge is of interest as being an old channel on one side of an ancient island in the Mississippi. The channel on the other side was larger and cut back to the head of the island more rapidly, thus tapping the supply of water for the smaller channel and leaving a deserted gorge which ends abruptly in a steep bluff some distance above where Minnehaha creek enters it.

In the vicinity of **St. Paul** and **Minneapolis** the Trenton formation contains some soft green shales, which are very rich in well preserved fossil remains; a few gasteropods, lamellibranchs, crinoids, and trilobites are found; also a considerable number of brachiopods and large quantities of bryozoans. In the limestone itself remains of gigantic Orthoceratites are often seen.

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* For a more detailed description of these differences see the pages relating to the recession of the Falls of St. Anthony.

MINNEAPOLIS TO MOORHEAD.

By Uly S. Grant.

Station.	Distance. Miles.	Distance. Kilometres.	Elevation. Feet.	Elevation. Metres.	Population.	Station.	Distance. Miles.	Distance. Kilometres.	Elevation. Feet.	Elevation. Metres.	Population.
Minneapolis	0	0	813	248	164, 738	Aldrich	138	222	1, 327	404	69
Fridley Park	7	11	847	258	....	Verndale	142	228	1, 349	411	635
Anoka	18	29	878	268	4, 252	Wadena	148	238	1, 350	411	95
Itaska	25	40	885	270	....	Wadena Junction	150	241	1, 352	412	....
Elk River	30	48	893	272	679	Bluffton	153	246	1, 323	403	....
Baileys	35	56	913	278	....	New York Mills	161	259	1, 410	430	260
Big Lake	38	61	935	285	....	Richland	166	267	1, 396	425	....
Becker	47	76	972	296	....	Perham	172	277	1, 370	417	761
Clear Lake	53	85	991	302	....	Frazee	183	295	1, 389	423	....
St. Cloud	65	105	1, 025	312	7, 686	McHugh	188	303	......	.....	....
Sauk Rapids	66	106	1, 005	306	1, 185	Detroit	193	311	1, 364	416	1, 510
Rices	79	127	1, 062	324	....	Audubon	200	322	1, 310	399	156
Royalton	86	138	1, 080	329	528	Lake Park	206	331	1, 356	407	....
Gregory	92	148	1, 100	335	....	Hillsdale	211	339	1, 197	365	....
Little Falls	97	156	1, 117	340	2, 354	Winnipeg Junct'n	214	344	1, 181	360	....
Darling	101	161	1, 154	352	....	Hawley	217	349	1, 151	351	270
Randall	107	170	1, 178	359	....	Muskoda	221	356	1, 090	322	....
Cushing	112	180	......	.....	....	Glyndon	230	370	925	282	275
Lincoln	118	190	1, 281	390	....	Tenny	233	375	922	281	....
Philbrook	125	201	......	.....	....	Dilworth	235	378	909	207	....
Staples	131	211	1, 274	338	....	Moorhead	239	384	905	276	2, 088

Immediately after leaving the Union Station at **Minneapolis** the rail road passes through a small cut in the upper beds of the Trenton limestone, and a small area of this is also seen just after crossing the river. A mile or two distant on the right, low-lying morainic hills are distinctly seen. The road then enters a level sandy plain of modified drift, and no more Paleozoic strata are seen within the State. This flat land is more or less covered by small scraggly oaks, commonly known as "scrub oaks," and continues until after passing **Anoka**.

At **Anoka** the Rum river, a small but important lumber stream, is crossed; but no rock is visible, as the river bed is confined entirely to Pleistocene deposits. Between **Anoka** and East **St. Cloud** the road continues in an area of modified drift, more or less rolling; but at **Elk River, Baileys,** and **Becker** hills of morainic accumulations are seen at the right of the track.

The first of the Archean rocks are entered a few miles southeast of **St. Cloud.** This area is only a few miles in extent, but a much larger area is seen at and near **Sauk Rapids** and Watab. The rocks are entirely granites, syenites, and gneisses, and are quarried quite extensively, especially at the former town.

From **Sauk Rapids** to **Little Falls** an area of modified drift extends for some distance on each side of the road. At this place the Mississippi is again crossed and a small area of slate, mica-schist, and diorite is seen along the river; these rocks are all Archean, but their exact horizon has not been determined. They cause the rapids in the river. A few miles south of **Little Falls** the southwestern limit of the evergreen forest is crossed; scattered pines have been seen farther south, but here they appear in large amounts. The principal species is *Pinus banksiana*, black pine, more commonly known as the "jack pine." It rarely grows to be of sufficient size for good lumber.

At **Little Falls** the Mississippi is again crossed and the railroad now runs directly away from the Father of Waters, taking almost a northwesterly course to the western edge of the State. From **Little Falls** to **Staples** a region of rolling and often hilly morainic country is passed through.

From **Staples** to **Perham** a flat to undulating area of modified drift is crossed, excepting that there is a small hilly morainic area between **New York Mills** and **Perham.** Before reaching the latter place the southwestern limit of the evergreen is again crossed, and only a small area of deciduous forest is seen before entering the prairies of the western part of the State. Otter Tail county, in which are situated the two last named towns, is crossed by an elevated morainic range of hills, the highest in the western half of the State. This elevated region is known as the Leaf hills, and is thickly dotted with numerous crystal lakes. In Otter Tail county these lakes cover more than one-ninth of the surface of the county. This lake area is entered just beyond **Perham** and continues to and beyond **Lake Park** in Becker county.

In the vicinity of **Lake Park** the prairie has become fully established and no more timber is seen except along water courses. Beyond this place a more flat or undulating area of till is entered and the descent toward the Red River of the North is begun.

One-fourth of a mile (.4 km.) east of **Muskoda** the first of the ancient beaches of Lake Agassiz is crossed. This is a low, gracefully rounded beach-ridge of gravel and sand, called the Herman beach. Then a plain, two miles (3.2 km.) in width, representing an old delta deposit, is crossed before reaching the second or Norcross beach. A mile (1.6 km.) beyond this the Campbell beach is crossed, and about a quarter of a mile (.4 km.) further is the McCauleyville beach; the latter is seen just before coming to the Buffalo River. The low flat valley of the Red River of the North is now entered and the road runs in a straight line directly west to **Moorhead,** a distance of 13 miles (21 km). The ground here is almost as level as a table, and the streams have cut but shallow narrow troughs in it. Between **Moorhead** and **Fargo** the Red River, a sluggish stream, is crossed.

ARTESIAN WELLS OF EASTERN DAKOTA.

By Geo. H. Eldridge.

A most remarkable series of artesian wells is developed in two belts of country coinciding in a general way with the meridional valleys of the Red River, which the road crosses at **Fargo** and **Moorhead**, and of the James River, which is passed at **Jamestown**, about 100 miles farther west.

The geological horizons from which the wells derive their waters are: (1) The Pleistocene drift of the Red River valley. (2) The middle and upper portions of the Cretaceous. (3) The Dakota sandstone which forms the base of the Cretaceous system on the Great Plains. (4) The Cambrian sandstones.

The last of these affords but a single well, which is in the Red River valley, 100 miles (161 km.) north of the railroad. It has a total depth of 915 feet (279 m.), of which the last 12 feet are in granite. It obtains fresh water at 503 feet (151 m.) and salt water at 903 feet (271 m.)

The Pleistocene wells are confined to the Red River valley, and obtain their water from seams of sand and gravel in the glacial till at depths of 85 to 270 feet (26 to 82 m.) These wells are developed in a belt 375 miles long. Fresh water is obtained from the southern portion of the belt, brackish and alkaline waters from that to the north of Blanchford, in North Dakota. The source of these waters is not distant, and the supply depends on the rainfall and the configuration of the immediate region.

The Middle and Upper Cretaceous wells are limited in number, and, with one exception, are also located in the Red River valley. They are from 250 to 395 feet (76 to 120 m.) deep, and their water flow is copious but brackish.

The Dakota sandstones supply the most important series of wells, which occupy a belt, along or adjacent to the James River valley, extending from Yankton, on the Missouri River, to Devil's Lake, north of **Jamestown**, a distance of 400 miles (644 km.) The standstones are 200 to 400 feet (180 m.) thick, and lie at depths of from 600 feet (60 to 120 m.) in the southern to 1,500 feet (450 m.) in the northern portion of the belt. The wells are from 4½ to 6 inches (11.4 to 15 cm.) in diameter and the flow of water in some of the wells is 8,000 gallons (36,000 l.) per minute, at a pressure of 25 to 28 pounds per square inch. Their waters are utilized for running the machinery of mills, for city fire systems, and for irrigating, to a limited extent.

The geological structure of the basin, so for as known, is that of a gently dipping series of Cretaceous rocks, resting unconformably upon the Cambrian and Archean of northwestern Minnesota, and rising slowly towards the base of the Rocky Mountains, where the first outcrops of Dakota sandstones are 250 to 400 miles (400 to 650 km.) away and at elevations of 3,000 to 5,000 feet (900 to 1,200 m.) above sea level.

THE GREAT PLAINS OF THE NORTH.

GENERAL SKETCH.

By Arnold Hague.

From Jamestown to the base of the Rocky Mountains the route crosses the Great Plains and affords an excellent opportunity to see this characteristic physical feature of the continent, which extends from British America to the southern boundary of the United States. The country traversed is singularly uniform in its general aspect, and to most travelers appears monotonous and dreary. It is gently undulating, and, save along the great drainage channels, presents but few rock exposures. With the exception of a few favored localities sheltered from the wind, the Great Plains are destitute of trees, but for the most part covered by a luxuriant growth of nutritious grasses.

One interesting feature of the route followed during the day is the gradual emergence of erosion topography from the distinctive drift topography which characterizes the ride across Wisconsin and Minnesota.

West of Jamestown the railway gradually ascends the Missouri coteau, a line of broad, but low, gently sloping hills of rounded ridges, extending along the east side of the Missouri River all the way from Bismarck southward to Pierre, the capital of South Dakota. Immediately bordering the Missouri the hills present a series of precipitous bluffs facing the valley. Taken together these undulating ridges form an elevated mass separating the broad, deep valley of the Missouri from the shallow parallel valley of the James.

The drift which near James Valley more or less completely masks the underlying sandstone ridges gradually thins out westward. It may be recognized by low lines of gravel stretching across the plains, resting unconformably upon the underlying sandstones. Frequently it takes on a morainal aspect in the form of wide belts of north and south trend. Beyond the Missouri River the drift expresses itself only in a thin, irregular mantle, from a few feet to a few inches in thickness, accompanied by quartz boulders. The drift finally disappears beyond Sims Station, and erosion topography characterizes the whole region, finding its most characteristic expression in the Bad Lands, or Mauvaises Terres, so-called by the early Canadian fur-trappers on account of the obstructions they offered to the traveler who attempted to cross them. The

line of drift trends off to the northwest, and has not as yet been recognized along the Yellowstone valley.

Cretaceous strata form the greater part of the surface rocks all the way from the James Valley to the mountains. The divisions of the Cretaceous system recognized on the Great Plains and along the base of the mountains in Dakota and Montana are:

Series.	Subdivisions.	Prevailing rocks.
Livingston		Conglomerates, sandstones, and volcanic agglomerates.
Laramie		White sandstones, clays, and shales.
Montana	Fox Hills; Fort Pierre	Shales and limestones.
Colorado	Niobrara; Fort Benton	Shales and limestones.
Dakota		Sandstones and conglomerates.

The Laramie Cretaceous, the coal-bearing series of the Great Plains and the Rocky Mountain region, is the prevailing horizon, and only in a few limited areas along the line of travel do the underlying rocks come to the surface east of the Yellowstone River; from Jamestown to Livingston, a distance of over 650 miles (1,046 km.), seldom do any but Cretaceous rocks appear at the surface from beneath the drift.

The Laramie consists of coarse sandstones and shales, the former more abundant at the base of the series, where also most of the coal seams are found. This important series has been traced north and south almost continuously along the Rocky Mountain front within the boundaries of the United States, and in British America has been recognized in the valley of the Yukon River, stretching northward nearly to the Arctic Circle. South of the United States it is less definitely known, but coal seams of Cretaceous age which probably belong to this horizon have been observed at various points in Mexico and also in Central America. Westward, the Laramie Cretaceous extends through the various breaks in the front ranges to the one hundred and twelfth meridian. The Northern Pacific Railway crosses it at one of its broadest expansions. Under varying conditions the coal obtained from the beds of this series range from a dry, porous, non-coking coal of very low specific gravity, through slightly caking coal, to a fairly dense coal affording an excellent quality of coke, and, in limited areas, to an excellent anthracite. Nearly 5,000,000 tons of coal were mined in these beds during the census year 1890.

Near the base of the mountains the Upper Cretaceous has been divided into two distinct groups which have been designated as the Laramie and the Livingston. The former is mainly a normal white sandstone composed of quartz grains; the latter is made up largely of

coarse conglomerates, with intercalations of somber-colored volcanic material composed of fine and coarse basic agglomerates, and beds of fine sands and clays deposited in shallow water and derived from the denudation of land surfaces. The Livingston rests unconformably upon the Laramie and contains pebbles of Archean schists, Paleozoic limestones, and Cretaceous sandstones. Away from the mountains the two groups have not as yet been differentiated.

The railway, which for the greater part of the distance (save, for instance, when crossing the Bad Lands) traverses the top of the gently undulating surface, on reaching the Yellowstone Valley follows the river between high bluffs of Laramie sandstone. At a number of localities along the river, Cretaceous rocks older than the Laramie are exposed in the bluffs. Near the mountains the entire series of Cretaceous strata, from the base of the Dakota to the Livingston, are upturned and well shown in excellent cross-section along ravines cut by streams coming down from the mountains.

On a bright clear day the first glimpses of the Rocky Mountains may be had from Billings, snow-clad peaks standing out prominently both to the north and south, and three or four hours before reaching Livingston the Bear Tooth Mountains to the south present a grand panoramic view of rugged peaks stretching along the horizon as far as the eye can reach. These mountains, whose summits reach 12,000 feet (3,658 m.), and their western extension, the Boulder plateau, 10,000 feet (3,048 m.), consist of Archean gneiss and granite. The slopes and foothills are made up of Paleozoic strata dipping either to the north or east, and passing beneath Mesozoic beds, the uppermost members of the Laramie standstone extending far out upon the plain. The Boulder plateau is intimately connected with the Snowy range, along the northern base of which the railroad runs from Big Timber to Livingston.

On the north side of the valley rise the Crazy Mountains, an isolated group standing out boldly from the main Rocky Mountain ranges. The central portion of these mountains consist in great part of igneous rocks that have broken through a broad synclinal trough of sandstones and shales, made up of a great thickness of sediments of the Livingston and overlying series of beds. From the central core of igneous rocks innumerable dikes have penetrated the sandstone, baking and hardening the sedimentary rocks, which have resisted erosion more than the easily friable beds.[35] The most southern peaks of the Crazies are situated about 15 miles (24 km.) north of the river, and are easily accessible to anyone desiring to study them.

FROM JAMESTOWN TO LIVINGSTON.

ITINERARY.

BY ARNOLD HAGUE.

Station.	Distance.		Elevation.		Station.	Distance.		Elevation.	
	Miles.	Kilometers.	Feet.	Meters.		Miles.	Kilometers.	Feet.	Meters.
Jamestown	0	0	1,395	425	Little Missouri	256	412	......	......
Eldridge	7	11	1,541	470	Sentinel Butte	272	438	2,707	825
Cleveland	20	47	1,794	547	Allard	312	502	2,246	685
Crystal Springs	37	60	1,792	546	Glendive	322	518	2,069	631
Dawson	50	80	1,748	533	Hoyt	337	542	......	......
Steele	58	93	1,859	567	Terry	361	581	2,242	683
Sterling	77	124	1,867	569	Ainslie	381	613	2,274	693
Bismarck	101	161	1,670	510	Miles City	400	644	2,355	718
Mandan	106	172	1,646	502	Forsythe	446	718	2,514	766
Sweet Briar	122	196	1,806	551	Howard	456	......	......	......
Sims	142	229	1,962	598	Custer	494	795	2,727	831
Kurtz	159	256	2,025	617	Billings	547	880	3,117	950
Gladstone	205	330	2,348	716	Park City	570	......	......	......
Dickinson	216	358	2,405	733	Big Timber	628	1,011	4,072	1,241
Belfield	236	380	2,579	786	Springdale	643	......	......	......
Sully Springs	247	397	2,575	785	Livingston	663	1,067	4,487	1,368

Jamestown is an attractive settlement and the center of an important wheat region, situated on the James River, a stream which running southward empties into the Missouri. From **Jamestown** west to **Bismarck,** the road for 100 miles (161 km.) passes over an undulating, grassy country, in every way characteristic of the Great Plains of the north. Leaving **Jamestown** the road gradually ascends, 450 feet (137 m.) in 20 miles (32 km.), to **Cleveland.** This is followed by gently rolling country for 50 miles (80 km.) to **Sterling,** from which point there is a gradual descent of 200 feet (60 m.) to the Missouri River. The glacial drift which everywhere covers the country east of the James Valley, gradually thins out to the west and south, and is lost as a continuous sheet before reaching the Missouri River. Drift in the form of small boulders may be easily recognized along the route, and is well shown near **Crystal Springs.** All the way from **Jamestown** to **Bismarck** the underlying rocks, as far as yet recognized, belong to the Laramie series, the beds becoming more and more marked as the Missouri is approached.

Bismarck, the capital of North Dakota, lies on the bluffs of the Missouri, which afford commanding views both up and down the broad valley.

Crossing the Missouri River by a fine bridge, good exposures of the Laramie may be seen in the bluffs on both sides of the river and back of the town of **Mandan**. Fox Hills strata occur along the river a few miles below **Bismarck**, but are not visible from the railroad; north of the railroad only Laramie strata occur.

Upon leaving the Missouri the train winds up the valley of Heart River, a small tributary of the main stream, coming out again upon broad plains much like those crossed on the east side of the Missouri. In many of the buttes and low hills one may observe a marked reddening of the strata. This is due to the heat which has resulted from the spontaneous combustion of the beds of lignite which are scattered throughout the Laramie. While some of these beds are now on fire, according to Dr. C. A. White many of them were burned out as long ago as Tertiary time, before the larger part of the great erosion occurred which produced the present configuration of the surface. Slag and ashes, the product of these early burnings, are now scattered upon the surface of even the highest of the hills, whence the softer material has been carried away.

At **Sims**, about 40 miles (64 km.) west of the main Missouri River, the first workable coal seams are seen. The mines here have been extensively opened and furnish a large amount of coal for locomotive purposes.

From the Missouri River there is a gradual rise of 450 feet (137 m.) in about 30 miles (48 km.), then a descent of 200 feet (61 m.) in 20 miles (32 km.) to **Curlew** Station. Rolling, monotonous country follows from **Curlew** to **Fryburg**, a distance of 90 miles (145 km.), and from **Fryburg** there is a descent of 500 feet (152 m.) in 15 miles (24 km.) to the Little Missouri River.

The Little Missouri River is the most important drainage channel between the Missouri and the Yellowstone. It takes its rise at the northwest extremity of the Black Hills, and follows a northerly course for 50 miles (80 km.) beyond the railroad, then bends eastward. In descending to the Little Missouri one passes through a small but characteristic area of *mauvaises terres* or bad lands. While these are by no means as extensive or impressive as those which characterize many of the great Tertiary basins of Wyoming, they present similar physical features and identical forms of erosion. For varied coloring and exquisite delicacy of tint they are most remarkable and unsurpassed by any similar country elsewhere.

Between the Little Missouri and the Yellowstone there is an ascent of 575 feet (175 m.), followed by a descent of over 800 feet (244 m.) to the latter river. All the country between these two streams is similar to that already passed over, but its surface is more broken, more diver-

sified and picturesque, and dotted over by isolated buttes and long ridges of low hills, sculptured forms left by erosion.

The railroad crosses the boundary line between the States of Dakota and Montana just west of **Sentinel Butte** station. Sentinel Butte lies a few miles south of the railroad and is plainly visible to the tourist, standing out upon the plain a most impressive object, like a monument on the desert. Geologically, it presents much of interest, as its base is composed of the upper beds of the Laramie, and it is capped by conformable strata of fresh-water deposits regarded as of early Eocene age.

The railroad reaches the Yellowstone valley at **Glendive,** and from here it follows the river all the way to **Livingston,** a distance of 340 miles (547 km.), with a gradual ascent of over 2,200 feet. The valley between the bluffs varies from 1 to 6 miles in width, the river meandering from side to side. Several large tributaries to the Yellowstone which enter the river from the south are crossed, including Powder river, Big Horn, Clarks Fork, and Stillwater. The first named rises between the Black Hills and the Big Horn mountains; the second drains the Big Horn mountains; and Clarks Fork and the Stillwater have their source in the Absaroka range. The railroad crosses the river three times, and for the greater part of the distance follows along under the bluffs on the south side. The Yellowstone valley above the bluffs presents much the same physical features as seen in eastern Montana, and the geological features offer but little in the way of change to break the dull monotony. The bluffs and low-rolling hills are formed of yellow sandstone, for the most part horizontal. It is the prevailing color of these beds that has given the name to the river, and consequently to the now famous Yellowstone Park, where the river has its source.

From **Glendive,** bluffs of Laramie sandstone may be seen stretching far down the valley, which has here a northeasterly direction. About 10 miles (16 km.) above **Glendive,** at the foot of the bluff on the east side of the valley, occurs an exposure of Fox Hills beds. These beds are determined by their organic remains, but are difficult to recognize, as lithologically they are similar to the overlying Laramie, and both series are conformable. There is exposed here the base of the Laramie, whereas the top of the series occurs at Sentinel Butte. According to Dr. C. A. White the thickness of the Laramie in western Dakota and eastern Montana is nearly 3,000 feet (914 km.).

Shortly after leaving **Miles City** the lignite beds crop out at the base of the Laramie; and at **Howard,** Fox Hill strata are said to come to the surface from beneath the overlying Laramie, but they are by no means easily distinguished.

At **Billings** the first important exposure of Middle Cretaceous is

encountered. Just east of the town the Fox Hills sandstones, together with the underlying Fort Pierre shales, are brought to the surface by an eroded anticline. The Pierre shales form the broad bottomland of the valley for several miles westward, and produce a marked contrast to the narrow valley and rugged inclosing bluffs of the Laramie. The town is built upon these Pierre shales that have been penetrated for 800 feet by an artesian-well boring. North of the town the shales form the smoothly sculptured base of a steep escarpment, being capped by a massive ledge, 75 feet in thickness, of Fox Hills sandstone, which is largely quarried and used as building stone in the town. Overlying the Fox Hills are the thinly-bedded gray sandstones of the Laramie, forming the highest cliffs bordering the river. Both series of sandstones present quite persistent bluffs on opposite sides of the valley, and about 25 miles (40 km.) west of **Billings** replace the Fort Pierre shales on the river bottom, the valley becoming narrow and canyon-like.

At **Laurel** a branch road crosses the river, running southward about 40 miles to the Red Lodge coal mines that supply the fuel used by the locomotives of the Northern Pacific Railway.[37]

West of **Park City** only Laramie rocks occur, but the country gradually becomes more rugged and the scenery diversified.

Big Timber, situated at the mouth of the Boulder, is built upon a broad terrace of Livingston deposits that extend back to the mountains, but have not as yet been traced more than a few miles to the east. The Livingston beds, however, stretch almost continuously as far west as the Bozeman Tunnel, through which the railway passes in crossing the Bridger range. The exposures of the interbedded volcanic agglomerates, largely made up of andesitic material, may be seen in the bluffs just west of **Springdale**, where the beds dip at an angle of 20° to the northeast. At one locality these agglomerates attain a thickness of 2,000 feet. Just beyond this place the railroad passes through a short ravine, showing an anticline of bedded clays and sandstones that form the base of the Livingston, the rocks being much disturbed, showing local folds and flexures.

Sheep Cliffs, just north of the river and midway between **Springdale** and **Livingston**, are especially interesting, as they show a massive sheet, of theralite intruded in the Livingston sandstone. This rare rock is here exceedingly fine-grained, almost black in color, with porphyritic crystals of augite and biotite; nepheline crystals only occur in the dense ground-mass of the rock. Much larger masses of this rock occur as intrusive sheets in the sandstones of the Crazy Mountains[35] to the north.

At **Livingston** the railroad crosses the Yellowstone for the last time, and immediately begins the ascent of the first range of the Rocky Mountains.

YELLOWSTONE VALLEY.

FROM LIVINGSTON TO CINNABAR.

ITINERARY.

Station.	Distance.		Elevation.		Station.	Distance.		Elevation.	
	Miles.	Kilometers.	Feet.	Meters.		Miles.	Kilometers.	Feet.	Meters.
Livingston			4,487	1,368	Daileys	31	50	4,915	1,498
Brisbin	10	16	4,682	1,427	Sphinx	41	66	5,065	1,544
Chicory	20	32			Cinnabar	51	82	5,179	1,579
Emigrant	23	37							

[By Walter H. Weed.]

At **Livingston** the train leaves the main transcontinental route and passes over the Yellowstone Park branch of the Northern Pacific railroad to **Cinnabar**, a distance of 51 miles (82 km.). It travels up the Yellowstone river through a picturesque mountain valley, with high peaks on both sides. Those east of this valley and south of **Livingston** are known as the Snowy range.

That portion of the Snowy range seen from **Livingston** is really the front of the Rocky Mountains, which farther westward bend north and extend in a nearly continuous range to the Canadian line and to the east bend southeastward for 75 miles between the Yellowstone river and Clarks Fork. The peaks seen from the town show the folded Paleozoic limestones dipping at steep angles northward and passing beneath the less steeply inclined Mesozoic beds that extend outward into and form the valley. The front of the range is characterized by a fold, in general parallel to the Archean contact, the anticline being often faulted, and west of **Livingston** passing into several *en echelon* anticlines with steeply pitching axes. The highest point seen south of the town, locally known as Baldy, is a sharply defined mass of Archean schist brought into contact with Carboniferous limestone by a faulting of the anticlinal fold just alluded to. The general structure is shown in the section (Fig. 14–A, p. 330), which passes through this mass.

Livingston, situated on the north bank of the Yellowstone river, is one of the many towns of the West born on the advent of the railroad, but rapidly growing with the settlement of the surrounding country. The town is built upon an alluvial river terrace, cut in the upturned

sandstones and grits of the Livingston series,[36] beds that consist of water-laid strata composed of andesitic material. These beds rest in apparent conformity upon the true Laramie, the horizon of the workable bituminous coal seams, but an unconformity is proven by the variety of pebbles of Paleozoic and Mesozoic rocks found in the conglomerates, and is actually shown in the mountains to the westward. The greatest thickness of the Livingston yet measured is 7,000 feet, the overlying sandstones and clays being quite distinct lithologically, and carrying a purely fresh-water fauna and a flora of Fort Union type. Plant remains are abundant in the Livingston beds, the species being largely of Laramie types. Specimens may be collected from the rocks forming the hills immediately north of the town, where characteristic exposures of the series occur. The overlying strata can be seen from these hills, forming low sandstone ridges and a light gray bluff wall to the northward, and the beds form the high peaks of the Crazy Mountains lying to the northeast.

South of the river a gently sloping alluvial terrace rises to the foot of the mountains, effectually concealing all exposures of the Middle Cretaceous rock except along the river banks.

The branch railroad to the Yellowstone Park traverses the valley bottom toward the gap in the mountains through which the river has cut its way to the Great Plains. On the west, low combs of sandstone belonging to the Middle Cretaceous are occasionally seen, the Laramie, Montana, and Colorado groups being passed before reaching the "Gate of the Mountains." The first beds attaining prominence are those of the Dakota Cretaceous, whose conglomerates form the crest of a striking east and west ridge, or "hog-back," dipping at 20° away from Canyon Mountain and separated from the mountain slopes by a persistent depression eroded in the soft fossiliferous shales and limestones of the Jurassic. The red sandstones, elsewhere considered Triassic, are not definitely recognized in this section, the first great ledge of the mountain being a quartzite assigned to the Carboniferous.

The canyon now entered affords easy access to the beautiful intermontane valley of the Yellowstone, bringing the traveler at once into typical Rocky Mountain scenery. The gorge is cut across an anticlinal fold whose southern half is faulted and crushed. The walls show a perfect section of the entire stratigraphic series from Cambrian to Jurassic. Underlying the prominent quartzite mentioned above are the massive heavily bedded limestones of the Carboniferous, here used for burning lime, and characterized by abundant fossils. Beneath these massive beds are the fissile limestones of the Devonian, resting upon limestones of doubtful Silurian age, that are in turn underlaid by limestones and shales containing an abundant typical Cambrian fauna. The series from Cambrian to Laramie Cretaceous is throughout conformable, no

gap or break appearing in this section. Near the south end of the canyon the beds of the west wall are repeated by local faulting, while those on the east side show considerable crumpling and pass beneath the Devonian and Carboniferous limestones that form the two arches at the south end of the wall. The general section may be briefly summarized as follows:

		Feet.
Carboniferous	Quartzites and interbedded limestones	300
	Limestones	2,000
Devonian	Limestones and shales	300
Cambrian	Limestones with interbedded shales	650
	Shales	200
	Quartzite	100

Emerging from the canyon these Paleozoic limestones may be seen resting at steep angles upon the gneisses and schists to the east, the valley of Deep Creek having been cut along the contact. The roof-like surfaces of the limestones and the square-cut bluffs and walls show in strong contrast to the spires and uniform slopes of the schists. The immediate valley bottom shows a couple of hills of Paleozoic limestone rising above the alluvial gravels. To the west the faulted anticlinal of Canyon Mountain brings the schists into view, but the nearer hill slopes are formed of Cambrian limestones replaced farther south by Devonian and Carboniferous beds, which an overthrust fault has superimposed upon the sandstones of Jurassic and Dakota Cretaceous. Near Brisbin an east and west ridge is formed of an anticline of Carboniferous limestones, the Mesozoic beds on its southern side passing beneath the dark-colored volcanic breccias and agglomerates that form Antelope Butte. From here southward the sedimentary formations are not seen until Cinnabar Mountain is reached near the railroad terminus.

The valley entered presents the most imposing scenery yet encountered; inclosed between the serrated crests of the Snowy Mountains upon the east and the more distant peaks of the Gallatin range upon the west, it stretches southward some 30 miles to the Archæan gorge of Yankee Jim canyon. Eroded along the line of a great fault the valley has long been the drainage way for the waters of the mountainous region to the south. The site of a Neocene lake whose sediments only remain where protected by a basaltic lava flow, it was filled by an ice sheet that flowed northward from the great plateau of the park, and its present most striking features were imposed upon it at this time. As the morainal deposits of this glacier, and the sculpturing effected by it, form a prominent part of the geology of this region, a somewhat full account is given of the glaciation of the valley at the end of this chapter.

West of the valley the peaks of the Gallatin range rise above retreating slopes, dotted with groves of pines and trenched by deep and narrow gorges. The range is eroded in a great accumulation of vol-

canic breccias, the rocks being basic andesites and lava flows similar to those described in the Snowy Mountains. The colors are usually dark, but rarely brilliant brick reds and purples prevail, as will be noticed on the slopes west of Daileys. The tufaceous beds often contain plant remains, and silicified tree trunks are not uncommon, together with agates, amethysts, and chalcedony. Hyalite is abundant and remarkably fine specimens have been obtained from the summits.

[By J. P. Iddings.]

The railroad from Livingston to Cinnabar passes in view of a transverse section across the end of the Snowy range, cut nearly at right angles to the strike of the beds. The general geological structure of the range is that of an anticlinal fold, the upper portion of which has been entirely removed by erosion, and which has been variously modified by faulting, especially at the southwestern end. The main body of the range consists of crystalline schists and granite, forming a high plateau and still higher peaks that reach 11,000 and 12,000 feet in altitude. Along the northern and southern flanks of the range the overlying Paleozoic strata dip away from the crystalline axis. While this is the structure of the greater part of the range it does not obtain for that portion of it passed in review by the railroad south of the main axis.

On the east, south of Deep Creek, a chain of rocky and precipitous peaks extends for about 12 miles to Mill Creek. These mountains consist of Archæan gneisses and schists, and constitute the end of the core of the great Bear Tooth range. They are extremely rugged, with narrow gorges or gulches cutting deeply into their mass. Their highest summits are 11,000 feet in altitude, or a little over 6,000 feet above the river level. Each of the great gulches has once been occupied by a glacier whose lateral moraines may be seen stretching far down into the open valley. The upper portions of the mountains are bare and forbidding and few of the summits have ever been ascended. Back of these peaks, to the east, the crystalline schists extend in a broad, flat-topped mass whose surface constitutes a high plateau 10,000 feet in altitude, but which has been dissected by canyons 3,000 or 4,000 feet deep. The surface of the plateau is finely glaciated and is covered with ponds and lakes, the rocks being almost completely destitute of soil or vegetation.

The most southern and highest peak of these gneissic mountains is Mount Cowen, 11,190 feet in altitude. It is immediately north of the valley of Mill Creek, opposite Chicory station. At the southern base of Mount Cowen is a double fault that has thrown down the country south in two displacements of over 3,000 feet each. These faults, and one at the south base of Sheep Mountain, have destroyed the anticlinal

character of the main range in this vicinity. The Mill Creek faults disappear 9 miles east of Mount Cowen, from which point the anticlinal structure extends eastward.

A cross section of the region from near the mouth of Mission Creek on the Yellowstone River, 9 miles below Livingston, through Livingston Peak and Mount Cowen to Mill Creek (Fig. 14–A), will aid in the understanding of the geological structure of this part of the region. It exhibits the Paleozoic strata dipping steeply north and passing under less highly inclined Mesozoic beds that form the broad valley of the Yellowstone below Livingston. A slight fault crossing the peak south of Livingston Peak has thrown down the sedimentary strata against the crystalline schists for a short distance. It shows the great body of schist and granite forming the mountains along the east side of Yellowstone Valley to Mount Cowen and the faults at its southern base.

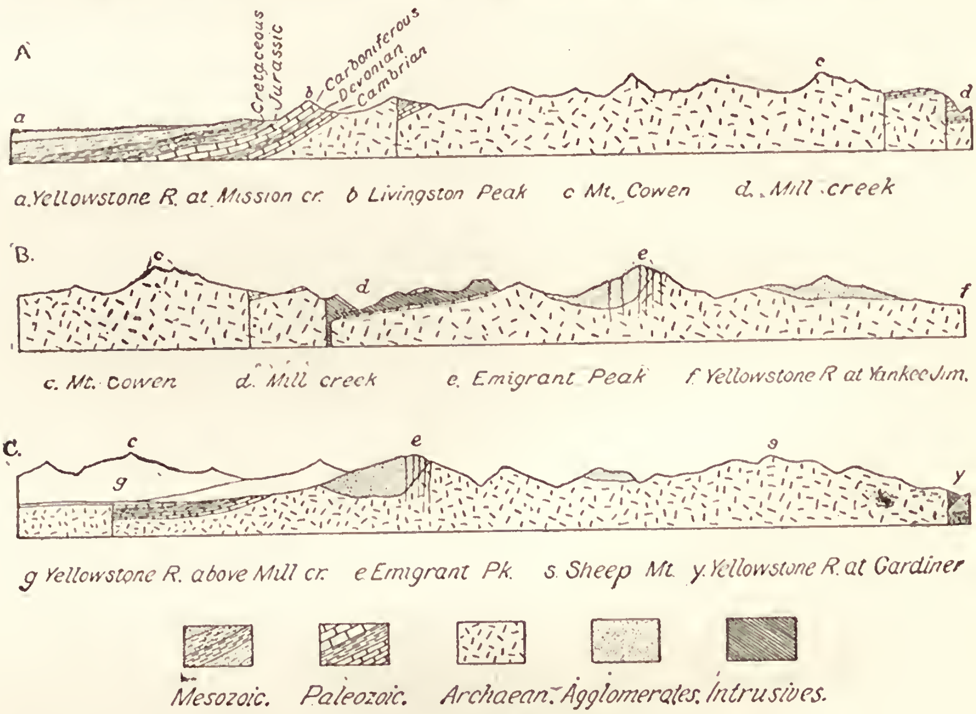

FIG. 14.—Snowy range sections.

The valley of Mill Creek opens a vista into the region of volcanic tuffs and breccia, mountains of which, 20 miles distant, may be seen from the railroad just north of Chicory station. The peaks a short distance back from the mouth of this valley consist of igneous rock that was intruded within sedimentary rocks and which undoubtedly rose along the fault plane at the base of Mount Cowen. Similar intrusive rock forms the high peak, Chico Mountain, between Mill Creek and Emigrant Gulch, the deep valley immediately north of Emigrant Peak

(10,960 feet—3340 m.) The limestone is exposed at the northwestern base of Chico Mountain, the main mass of igneous rock having been intruded in shale that lies near the base of the Cambrian deposits near the gneiss. From this point southward to Yankee Jim canyon, and beyond the great mass of the mountains east of the river, is gneiss and schist, upon the ancient surface of which volcanic ejectamenta have accumulated. The extremely uneven character of the gneissic country at the time of the volcanic outbreaks and the irregularities of subsequent erosion explain the present geological structure of this part of the region.

Emigrant Gulch, near its mouth, cuts 2,000 feet into crystalline schists that are exposed in a low belt around the northwestern base of Emigrant Peak. Above this andesitic tuff breccia or agglomerate rises for 5,000 feet to the summit of the mountain; while on the southern side gneiss rises to within 1,200 feet of the summit. The andesitic breccia at the summit is traversed by dikes of porphyrite with a general northwest and southeast trend. The more prominent may be seen from the railroad. The breccia has been indurated by the proximity of great bodies of intruded porphyrite which form mountains east of Emigrant Peak, which accounts for its having withstood erosion and having become one of the loftiest peaks in the region. (Fig. 14–B and C.)

South of Emigrant Peak, Six-Mile Creek has cut deeply into crystalline schists and granite. The mountain ridges surrounding its drainage basin consist of andesitic breccia, tuffs, and lava flows, which cap the granite at about 7,000 feet along the east side of the valley. The crystalline schists are well exposed in the narrow gorge through which the river runs at the southern end of its broad valley, and which is known as Yankee Jim canyon. The gneisses cross to the western side of the river, and are overlaid by volcanic lavas, as on the eastern side.

The cross section of the country through Mount Cowen and Emigrant Peak (Fig. 14–B) exhibits the geological structure of the region just described, which needs no further comment except to note that the section crosses the faults at the base of Mount Cowen about 3 miles west of where the first section crosses them, and intersects a large body of intruded porphyrite.

From Yankee Jim canyon south for several miles, knobs of chocolate-colored breccia may be seen on both sides of the river resting upon gneiss. The light-colored rocks east of the river, opposite Cinnabar Mountain, are mainly decomposed gneiss overlaid by some igneous rocks and cut by dikes of the same. The gneiss has been greatly fractured by joints representing the termination of a profound fault which exists farther south.

The high mass of Sheep Mountain opposite Cinnabar station is crystalline schist from base to summit, which is 10,628 feet in altitude.

These rocks continue to form high mountains along the northern side of the Yellowstone River east of Gardiner. The peaks surrounding the head of the valley of Bear Creek opposite Gardiner are volcanic ejectamenta and intruded bodies of porphyrite. The bench at the base of Sheep Mountain, about 600 or 800 feet above the river, consists of a lava flow of basalt resting on the upturned edge of faulted Cretaceous sandstones. Small wedges of these rocks have settled short distances and lowered parts of the basalt sheet to different levels, so that it appears from the south side of the river as though there were a number of superimposed sheets. The light-colored deposit upon the basalt is the remains of an ancient travertine, similar to that at Mammoth Hot Springs. A profound fault passes along the south base of Sheep Mountain in a southeast and northwest direction, the displacement being over 6,000 feet. This fault is shown in the cross section through Emigrant Peak and the summit of Sheep Mountain (Fig. 14–C). The geological structure is exceedingly simple and is largely a repetition of that in the second section (Fig. 14–B). The northern end of the section crosses the Yellowstone River two miles above Chickory Station, where it probably intersects the Mill Creek fault.

[By Walter H. Weed.]

At Cinnabar Mountain the sedimentary rocks are again met with, a section being exposed from the Archean to the Laramie Cretaceous. The mountain received its name from a prominent band of bright red sandstone, the so-called Devils Slide, there being of course no mercury there. In the mountain the sedimentary strata are nearly vertical, being the sharply upturned end of a synclinal trough whose axis is the sag south of the mountain. It is the most convenient locality for the traveler to examine the stratigraphical section, as the rocks are well exposed and readily accessible. The northern part of the mountain is composed of Paleozoic limestones so closely compacted that the subdivisions are not easily recognized, but the quartzite at the summit of the Carboniferous, with its red magnesian limestones, is distinctly differentiated. Above these beds are the Triassic sandstones forming the Devils Slide, and the ripple-marked quartzite which overlies them forms the north wall of the most prominent of the gulches that seam the mountain side. The gray Jurassic shales are well exposed and contain an abundance of fossils characteristic of the Rocky Mountain Jura, such as *Myacites*, *Rhynchonella*, *Gryphæa*, *Camptonectes*, etc. It is in these rocks that the intrusives forming the south wall of the great gulch have been injected. Overlying these Jurassic beds are the grits and conglomerates of the Dakota Cretaceous, in which a limestone belt carrying fresh-water fossils may be seen. Above this the dark bituminous shales of the Fort Benton, with occasional arenaceous belts,

are exposed, overlain by the lighter shales and shaly limestones of the Niobrara, while the leaden clays of the Fort Pierre form the southern part of the mountain. Fossils, though not abundant, may be found. The Fox Hills is shaly and is overlaid by the lithologically distinct sandstones of the Laramie, in which the coal seams[37] worked at Horr are located. The coal is of excellent quality, occurs in a number of seams, and makes a remarkably pure and firm coke. To the southward the sharp summit of Electric Peak is seen, Cinnabar Mountain being but the northern end of a long spur of that peak. Across the river the Coal Measures of the Laramie dip steeply eastward and are covered by a sheet of modern basalt. A few openings show the same coal seams here as at Horr.

Glaciation of the Yellowstone valley.—The local glaciers formerly abundant in the Rocky Mountain Cordillera attained an unusually extensive development on the plateaus and encircling ranges of the Yellowstone Park, and, as will be shown in the account of that region, sent glaciers down the valleys that drained the highlands in every direction. Along the northern border two streams of ice, pushing northward, found an outlet for their united flow down the valleys of the Yellowstone River, and have left impressive evidences of their power and magnitude that at once attract the attention of the observant traveler.[38] These memorials of the vanished glacier present several features of interest not common in this portion of the Cordillera. The mountain valleys of the Yellowstone were carved out before their occupancy by ice, and the ice stream expanded in its lower portion, producing morainal heapings closely resembling those of the continental type. True mountain moraines, both lateral and terminal, and formed of angular débris, occur in tributary gulches cut in the Snowy range to the east, but they are entirely lacking in the valley proper. Westward the ice sheet crowded upon the flanks of the Gallatin range and left Archean and Paleozoic boulders resting upon the volcanic rocks.

On emerging from the gorge south of Livingston the train skirts the margin of an alluvial bottom, inclosed by stream terraces cut in the old overwash plain of the glacier. The glacial gravels have been largely re-sorted and form benches that are susceptible of cultivation when irrigated. To the east, local moraines formed by small glaciers from lateral gorges may be seen flanking the valley. From **Brisbin** to **Chicory** the higher terrace is part of the original overwash plain, somewhat modified where the larger mountain streams debouch into the valley. Seen from the railroad, its characteristic gentle slope and gravelly surface can be distinguished, but just before reaching **Chicory** the steep hummocks of the moraine may be seen rising abruptly from the terrace. These hills are from 15 to 25 feet in height, their slopes covered with boulders and gravel; they mark the extreme northward

termination of the Yellowstone glacier. Although several terminal moraines may be distinguished in places, there is too general an overlapping to permit of definite mapping of the successive positions of the ice front. In this part of the valley the sharply limited extent of the glaciation will be at once noted. To the east an extensive development of the overwash plain is seen, forming a flat dotted with farms between Mill creek and the river, with the hummocky surface of a strip of valley moraine at the base of the mountains.

East of the valley, the steep slopes of the Snowy Mountains show fine examples of mountain moraines upon their flanks, while their deeply incised canyons and polished slopes of gneiss show the abrading power of the tributary glaciers. West of the valley the rocks are wholly volcanic and readily distinguishable from the glacial drift. Near Fridleys (**Emigrant** station) the ice covered only the valley bottom, but as we ascend the valley toward the south the drift rises to higher altitudes, though nowhere does it creep far up the mountains. It is evident that the Yellowstone glacier once filling the valley was not reinforced by streams from the west.

Near Fridley's (**Emigrant**) the columnar cliffs of a recent basalt flow are seen. The lava caps Pliocene lake beds, and its upper surface is polished, planed, and striated by the ice sheet. Aross the river to the eastward a good example of a subglacial stream channel can be seen indenting the undulating morainal slopes. Approaching **Daileys** another exposure of basalt, capping lake beds, is seen to the east; boulders of basalt from the two localities are very abundant in the drift down the valley. To the west a remarkable series of terrace lines is seen, some thirteen being plainly distinguishable. They are found only within the glaciated area, and are due to diverted drainage, marginal to the ice. The valley presents very different features on its two sides. To the east the serrated summits of the Snowy mountains and the high point of Emigrant Peak rise abruptly from the valley. These mountains held tributary glaciers at one time confluent with the great glacier filling the valley, and at its decline pushing westward across the valley and depositing erratics of gneiss and limestone upon the slopes of volcanic agglomerate. The mountain slopes are strewn with scattered erratics, and striking examples of moraines of angular débris may be seen upon their flanks.

To the west of the valley, however, the limit of the drift is very sharply defined. The dark slopes of volcanic agglomerates rising gradually to the crest of the Gallatin range are free from drift and show no evidences of glacial sculpture. It is certain that the ice filling the valley extended but a short distance up the slopes. Within the drift-covered area the slopes are very generally terraced, and the evidence

is clear that it is due to the diversion of the drainage from the mountain slopes to the west by the ice, the resulting marginal streams cutting the terraces. In certain cases these streams have cut remarkable canyons transversely across the slopes; in some instances, a mile or so long and 50 feet deep. Both canyons and terraces are confined to the drift-covered area, whose topography is in strong contrast to the unglaciated slope above.

The valley moraine is of the kame type, and does not extend up to the bounding slopes upon which scattered erratics alone are found. This valley moraine is formed of more or less waterworn or subangular material, and differs from the angular débris forming the usual types of lateral mountain moraines. Such a moraine is seen at the south end of the valley near the mouth of Yankee Jim canyon and was formed during the retreat of the ice.

Yankee Jim canyon is an ice-cut gorge whose polished walls are emphatic witness to the magnitude and power of the ancient glacier. Upon these glaciated surfaces *blocs perchés* can be seen at every favorable point. Not only did the ice fill this gorge to the brim, but the erratics on Dome mountain to the east and the higher slopes to the west show that it was here 3,000 feet thick and filled the adjacent valleys.

Cinnabar mountain was completely buried beneath the ice, and blocks of sedimentary rocks from its summit were carried southward and down the valley. Huge erratics of granite are abundant above the canyon and dot the slopes inclosing Cinnabar valley, but here the crowding of ice from Bear gulch, the Yellowstone and Gardiner rivers, and Cache creek has left a confused record. It is, strictly speaking, the beginning of the Yellowstone glacier, and from here southward glacial detritus and glacial sculpture will be observed throughout the park, an account of which is given in the chapter on that region.

THE YELLOWSTONE PARK.

By Arnold Hague.

The Yellowstone National Park is situated in the northwest corner of the State of Wyoming, with a narrow strip of country less than two miles in width in Montana on the north, and a still narrower strip extending westward into Idaho. Its boundaries, as determined by the act of Congress establishing the park, are ill-defined, as at the time of the enactment of the law the region had been little explored. Its relations to the physical features of the surrounding country were only slightly understood. It is probable that before many years Congress will readjust and clearly define the park boundaries, placing it entirely within the State of Wyoming. That portion of the Park most frequented by tourists lies south of the forty-fifth parallel of north latitude, and between the one hundred and tenth and one hundred and eleventh meridians of west longitude. For a long time the park country and the adjacent mountains remained an inaccessible land, which had defied all efforts of the early explorers to discover its secrets. The early fur trappers had been all around this unknown land, but they do not appear to have been attracted by it; the Indians never resorted there for permanent encampment, and as a dense forest growth covered the mountains it long remained an uninviting, trackless region. An occasional venturesome mountaineer entered the country, but not until 1870 was there any trustworthy account of a journey across its central portion. At that time the region was the largest tract of unexplored country in the Rocky Mountains. In 1871 Dr. F. V. Hayden, United States Geologist, visited the region, accompanied by a corps of skilled scientific assistants, including geologists, topographical engineers, and a photographer. His expedition was eminently successful, and immediately attracted the attention of the world. It must always redound to the credit of Dr. Hayden that he fully appreciated the exceptional character of the region and the advisability of its forever being held intact by the General Government. He laid the matter before the Congress of the United States, and upon his earnest solicitation the park was established.[39] In the organic act of 1872, defining the park, Congress declared that the reservation was "dedicated and set apart as a public park or pleasure ground for the benefit and enjoyment of the people." The wisdom and foresight of those who at that time urged the withdrawal from settlement of this tract of land from the public domain has never been questioned.

Since the setting aside of the region as a national park, the U. S. Geological Survey has done much towards investigating the natural phenomena found there.[40] The park is under the care of the Secretary of the Interior, who is authorized to carry out the provisions of the law, to make all rules and regulations for its protection and maintenance. The superintendent is a military officer, with headquarters at the Mammoth Hot Springs.

The area of the Yellowstone Park[41], as at present defined, is somewhat more than 3,300 square miles. The central portion is essentially a broad volcanic plateau between 7,000 and 8,500 feet above sea level, with an average elevation of 8,000 feet. Surrounding it on the south, east, north, and northwest are mountain ranges with culminating peaks and ridges rising from 2,000 to 4,000 feet above the general level of the inclosed table-land. Beyond the mountains the country falls away in all directions, the lowlands and valleys varying in altitude from 4,000 to 6,000 feet above sea level.

The Gallatin range incloses the park on the north and northwest. It lies directly west of the Snowy range, only separated by the broad valley of the Yellowstone River. It is a range of great beauty, of diversified forms, and varied geological problems. Electric Peak, in the extreme northwestern corner of the Park, is the culminating point in the range, and affords one of the most extended views to be found in this part of the country. Archean gneisses form a prominent body on the west side of the range, over which occur a series of sandstones, limestones, and shales of Paleozoic and Mesozoic age, representing Cambrian, Silurian, Devonian, Carboniferous, Trias, Jura, and Cretaceous strata. Immediately associated with these sedimentary beds are large masses of intrusive rocks which have played an important part in bringing about the present structural features of the range. They are all of the andesitic type, but show considerable range in mineral composition, including pyroxene, hornblende, and hornblende-mica varieties. These intrusive masses are found in narrow dykes, in immense interbedded sheets forced between the different strata, and as laccolites. The valleys are deeply scored by ice, and the rocks of the range may be found strewn all along the Gardiner River and well out over the valley of the Yellowstone.

South of the Park the Tetons stand out prominently above the surrounding country, the highest, grandest peaks in the northern Rocky Mountains. The eastern face of this mountain mass rises with unrivaled boldness for nearly 7,000 feet above Jackson Lake. Northward the ridges fall away abruptly beneath the plateau lavas of the park, only the outlying spurs coming within the limits of the reservation For the most part the mountains are made up of coarsely crystalline

gneisses and schists, probably of Archean age, flanked on the northern spurs by uplifted Paleozoic rocks.

East of the Tetons, across the broad valley of the Upper Snake, generally known as Jackson Basin, lies the well-known Wind River range, famous from the earliest days of Rocky Mountain trappers. The northern end of this range is largely composed of Mesozoic strata, single ridges of upper Cretaceous sandstone penetrating still further north into the regions of the Park until buried beneath massive flows of lava.

Along the entire east side of the Park stretches the Absaroka range, so called from the Indian name of the Crow Nation. The range is intimately connected with the Wind River range, the two being so closely related that any line of separation must be drawn more or less arbitrarily, based more upon geological structure and forms of erosion than upon any clearly defined physical limitations. The Absarokas stretch for more than 80 miles, a rugged, unbroken mountain mass, without any good pass across them. They have always stood as a formidable barrier to all western progress, and to-day are only crossed by hunters and mountaineers by one or two dangerous trails known to but few. All the upper portion of the range is formed of eruptive rocks that have poured out in such enormous masses as to conceal an earlier range made up largely of Mesozoic and Paleozoic strata, extending from the Cambrian to the Upper Cretaceous. The latter are seen all along the east base of the range, and at the northern end in Clarks Fork valley, and in the Park at the junction of Soda Butte creek and the Lamar river.

At the northeast corner of the Park a confused mass of mountains connects the Absarokas with the Snowy range. This latter range shuts in the park on the north, and is an equally rough region of country, with elevated mountain masses covered with snow the greater part of the year, as the name would indicate. Only the southern slopes, which rim in the Park, bear upon the geology of the region. Here the rocks are mainly granites, gneisses and schists, with sedimentary beds, for the most part, referable to pre-Cambrian series. They are in great part overlain by Tertiary lavas.

The region has been one of profound dynamic action and a center of mountain building on a grand scale. So far as the age of these mountains is concerned, evidence goes to show that upheaval was contemporaneous in all of them, and coincident with powerful dynamic influences which uplifted the north and south ranges stretching across Colorado, Wyoming, and Montana. These dynamic movements blocked out for the most part the Rocky Mountains near the close of the Cretaceous, although there is good reason to believe that in the region of the Park profound faulting and displacement continued the work of mountain building into much later time. By the building up of these mountains a depressed basin was formed, everywhere inclosed by high

land. Later the pouring out of vast masses of lava converted this depressed region into the Park plateau. Tertiary time in the Park was characterized by great volcanic activity, enormous volumes of erupted material being forced out. This activity extended through the Pliocene period and probably well on into the Pleistocene. Within recent time there is no evidence of any extensive outbursts; indeed, volcanic energy may be considered long since extinct.

The volcanic rocks present a wide range in chemical and mineral composition. They may all, however, be classed under three great groups—andesites, rhyolites, and basalts.

Andesites have played a most important part in bringing about the present configuration of the mountains surrounding the Park plateau. As already mentioned, in the Gallatin range they form large masses, and most of the culminating peaks in the Absarokas are composed of compact basic andesites or agglomerates accompanied by basaltic flows. Andesites, however, are not confined to the mountains, but also forced their way to the surface in the interior depressed basin.

That the duration of andesitic eruptions continued through a long period of time is made evident by plant remains embedded in volcanic ashes and mud associated with layers of breccia and more or less compact lavas, which accumulated to a depth of nearly 2,000 feet. Much of this plant material is in an excellent state of preservation and it is in these beds that the well-known fossil forests occur. In the grand escarpments along the Lamar valley the forest-bearing beds are admirably displayed, erosion having cut numerous lateral ravines and gorges in the lava beds, many trees still standing in upright position.

In late Cretaceous or early Tertiary times, a volcano burst forth in the northeast corner of the basin not far from the junction of the Absaroka and Snowy ranges. It rises from a base about 6,500 feet above sea level, the culminating peak attaining an elevation of 10,000 feet. This gives a height to the volcano of 3,500 feet from base to summit, measuring from the Archean rocks of the Yellowstone Valley to the top of Mount Washburne. The average height of the crater rim is about 9,000 feet above sea level, the volcano measuring 15 miles across the base. The eruptive origin of Mount Washburne has long been recognized, and it is frequently referred to as a volcano. It is, however, simply the highest peak among several others, and represents a later outburst which destroyed in a measure the original rim and form of an older crater. The eruptions for the most part were basic andesites and basalts. Erosion has so worn away the earlier rocks, and enormous masses of more recent lavas have so obscured the original form of lava flows, that it is not easy for an inexperienced eye to recognize a volcano, and that the surrounding peaks are the more elevated points in a grand crater wall. By following around the ancient andesitic rim, and

studying the outline of the old crater, together with the composition of its lavas, its true origin and history may readily be made out. This older crater has, as yet, received no special designation, but when our maps and reports are finally published, this ancient geological ruin will receive an appropriate designation. This old volcano occupies a prominent place in the geological development of the park, and dates back to the earliest outbursts of lava which have in this region changed a depressed basin into an elevated plateau. We have here a volcano situated far inland, in an elevated region, in the heart of the Rocky Mountains. It lies on the eastern side of the continent, only a few miles from the great continental divide which sends its waters to both the Atlantic and Pacific.

After the dying out of the andesitic lavas, followed by a long period of erosion, immense volumes of rhyolite were erupted which not only threatened to fill up the crater but to bury the outer walls of the volcano. On all sides the basic lava slopes were submerged beneath the rhyolite to a height of from 8,000 to 8,500 feet. These great flows of rhyolite did more than anything else to bring about the present physical features of the Park table-land. But few large vents or centers of eruption for the rhyolite have been recognized, the two principal sources being the volcano to which reference has already been made, and Mount Sheridan, a volcano in the southern end of the park.

Mount Sheridan stands unsurpassed as a commanding peak, rising grandly above the general level of the plateau, with an elevation of 10,200 feet above sea level and 2,600 feet above Heart Lake at its eastern base. From the summit of this peak on a clear day one may overlook the entire plateau country and the mountains which shut it in, while almost at its base lie the magnificent lakes which add so much to the quiet beauty of the region, in contrast with the rugged scenery of the mountains. From no point is the magnitude and grandeur of the volcanic region so impressive.

Taking the bottom of the basin at 6,500 feet above sea level, these acidic lavas piled up until the accumulated mass measured 2,000 feet in thickness. In none of the deep gorges like the Yellowstone, Gibbon, and Madison canyons, are the underlying sedimentary rocks exposed.

The Park plateau, built up of rhyolite flows, embraces an area 50 by 40 miles, with a mean altitude of 8,000 feet. Strictly speaking, in the common acceptation of the word, it is not a plateau; at least, it is by no means a level country, but an undulating region characterized by bold escarpments and abrupt edges of mesa-like ridges. It is accidented by shallow basins of varied outline and scored by deep canyons and gorges. The rhyolites rest against the steep slopes of the Absarokas and bury the northerly spurs of the Wind River and Teton ranges. On

both sides of the Gallatin range the rhyolites encircle sedimentary beds at about the same level. From Electric Peak to the Tetons, one may travel the entire distance of 60 miles without leaving the rhyolites. Nowhere, except in limited outbursts along the base of the Absarokas, do the rhyolites penetrate the mountains.

Although the rocks of the plateau for the most part belong to one group of acidic lavas, they by no means present the great uniformity and monotony in field appearance that might be expected. These 2,000 square miles offer as grand a field for the study of structural forms, development of crystallization, and mode of occurrence of acidic lavas as could well be found anywhere in the world. They vary from a nearly holocrystalline rock to one of pure volcanic glass. Obsidian, pumice, pitchstone, ash, breccia, and an endless development of transition forms alternate with the more compact lithoidal lavas which make up the great mass of the rhyolite, and which in color, texture, and structural development present an equally varied aspect. In mineral composition these rocks are simple enough. The essential minerals are orthoclase and quartz, with more or less plagioclase. Sanidine is the prevailing feldspar, although in many cases plagioclase forms occur nearly as abundantly as orthoclase. Chemical analyses, whether we consider the rocks from the crater of Mount Sheridan, the summit of the plateau, or the volcanic glass of the world-renowned Obsidian Cliff, present comparatively slight differences in ultimate composition.

Occasional thin sheets of basalt reached the surface before the completion of rhyolitic outbursts, flows of acidic lava overlying basic ones at several localities. In general, however, basaltic lava followed rhyolite. The basalt occurs near the outer edge of the rhyolitic mass, and in no single instance is there an extrusive flow of basalt in the central portion of the plateau.

After the close of the basaltic eruptions and the dying out of volcanic energy came the period of glaciation of the entire region. In the Teton range several characteristic glaciers still exist upon the slopes of Mount Hayden and Mount Moran, remnants of a much larger system of glaciers. Broad névé fields may be seen in the Bear Tooth mountains northwest of the Park. The Park region presents so broad a mass of elevated country that not only the surrounding mountains but the entire plateau was in glacial times covered with ice. Glacial lakes, kames, terminal moraines, and nearly all the phenomena of ice action usually seen in glaciated regions may be found here. A remarkable and exceptional feature, which is shown here on a grand scale, is the action of thermal siliceous waters on glacial drift.

Over the Absaroka range glaciers were forced down into the Lamar and Yellowstone valleys, thence westward over the top of Mount Evarts to the Mammoth Hot Springs basin. On the opposite side of the Park,

the ice from the summit of the Gallatin range moved eastward across Swan valley and passing over the top of Terrace mountain joined the ice field coming from the east. The united ice sheet plowed its way northward down Gardiner valley to the Lower Yellowstone, where the broad valley may be seen strewn with the material transported from both the east and west rims of the Park. It has been named the Yellowstone glacier.

A second powerful glacier moved southward over the plateau and down the broad valley of the Snake, receiving a number of tributaries from both the Wind River and Teton ranges.

Since the building up of the Park plateau, glacial erosion has greatly modified all surface features of the Park. It has broadened and deepened preexisting drainage channels, opened new waterways, and cut

FIG. 15.—Glacial boulder near the Yellowstone canyon.

magnificent gorges in the rhyolite plateau. Such gorges as the Yellowstone, Gibbon, and Madison canyons, in the strictest sense of the word, have all been carved out in recent time. These canyons are several miles in length and from 700 to 1,400 feet in depth.

To the geologist one of the most impressive objects on the Park plateau is a transported boulder of granite which rests directly upon the rhyolite near the bank of the Grand Canyon, about three miles below the Falls of the Yellowstone. In stands alone in the forest, miles from the nearest glacial boulder. Glacial detritus carrying granitic material

may be traced upon both sides of the canyon wall, but not a fragment of rock more than a few inches in diameter, older than rhyolites, has been recognized within a radius of many miles. This massive block, although irregular in shape and somewhat pointed towards the top, measures 24 feet in length by 20 feet in breadth and stands 18 feet above the base. The nearest point from which it could have been transported is distant 30 or 40 miles. Coming upon it in the solitude of the forest, with all its strange surroundings, it tells a most impressive story. In no place are the evidences of frost and fire brought so forcibly together as in the Yellowstone National Park.

Since the close of the glacial period no geological events have brought about any great changes in the physical features of the region other than those produced by the action of steam and thermal waters. Evidences of fresh lava flows within recent time are wholly wanting. Nevertheless, over the Park plateau the most unmistakable evidence of underground heat is everywhere to be seen in the waters of innumerable hot springs, geysers, and solfataras. A careful study of all the phenomena leads to the theory that the cause of high temperatures of these waters is to be found in the heated rocks below, and that the origin of the heat is in some way associated with the sources of volcanic energy. Surface waters in percolating downwards have become heated by relatively small quantities of steam rising through fissures from much greater depths. Geysers and springs return these meteoric waters to the surface. Thermal springs, geysers, and solfataras are in a sense volcanic phenomena, and remain as evidence of the gradual dying out of volcanic energy. If this theory is correct, proof of the long-continued action of thermal waters upon the rocks should be apparent, as it is fair to suppose that they must have been active forces ever since the cessation of volcanic eruptions. This is precisely what one may see all over the rhyolite area. Ascending currents of steam and acid waters have acted as powerful geological agents in rock decomposition and have left an indelible impression upon the surface of the country. Large areas of decomposed rhyolite and extinct solfataras show the former existence of still greater thermal activity. Rock decomposition and deposition of sediment from siliceous waters are extremely slow processes, if we may judge from what we see going on to-day in the different geyser basins. It is evident that to accomplish such changes a long period of time must have been required.

An evidence of the antiquity of the hot spring deposits is shown in an equally striking manner, and by a wholly different process of geological reasoning. Terrace mountain is an outlying ridge of the rhyolite plateau, just west of the Mammoth Hot springs. It is covered on the summit with thick beds of travertine, among the oldest portions of the Mammoth Hot springs deposits. It is the mode of occurrence

of these calcareous deposits from the hot waters which have given the name to the mountain. Lying upon the surface of this travertine on the top of the mountain are found glacial boulders brought from the summit of the Gallatin range, 15 miles away, which have been transported on the ice sheet across Swan valley and deposited on the top of the mountain, 700 feet above the intervening valley. They offer the strongest possible evidence that the travertine is older than the glacier which has strewn the county with transported material. How much travertine was eroded by ice it is, of course, impossible to say, but so friable a material would yield readily to glacial movement.

The number of hot springs found in the Park exceeds 4,000. If to these be added the fumaroles and fissures, from which issue in the aggregáte enormous volumes of steam and acid vapors, the number of active vents would be more than doubled. There are about 100 geysers in the Park. Between a geyser and a hot spring no sharp definition can be drawn, although a geyser may be defined as a hot spring throwing, with intermittent action, a column of water and steam into the air. A hot spring may boil incessantly without violent eruptive energy; a geyser may lie dormant for years without any explosive action and again break forth with renewed force

The thermal waters of the Park may be classed under three heads: first, calcareous waters carrying calcium carbonate in solution; second, siliceous acid waters usually carrying free acid in solution; third, siliceous alkaline waters rich in dissolved silica.

Calcareous waters are confined almost exclusively to the Mammoth Hot springs, where they have built up enormous deposits of travertine with only traces of salts of magnesia and alkalies. The travertine contains from 95 to 99 per cent of calcium carbonate. The Mammoth Hot springs lie just north of the northern escarpment of the Park plateau, and while they break out in close proximity to rhyolite bodies and undoubtedly receive their heat from volcanic sources, they reach the surface through Mesozoic strata, which here form the surface rocks. Jurassic and Cretaceous limestones have furnished the lime held in solution and precipitated as travertine. With a few insignificant exceptions, only siliceous waters are found issuing from fissures in the rhyolite rocks, from which they derive their mineral contents. Acid waters may usually be recognized by efflorescent deposits of alum and soluble salts of iron, and frequently by the presence of delicate crystals of sulphur. These acid waters possess an astringent taste. Although far less common than the alkaline waters, they occur scattered over the plateau at a number of localities and may be found at the Highland springs, on the west slopes of Mount Washburne, and in the Norris Basin. Alkaline springs present more of general interest than the acid waters, as it is only in connection with the former that the

geysers are found. They are the principal waters of all the geyser basins and of most of the hot spring areas. Alkaline waters deposit mainly amorphous silica as siliceous sinter, but in an endless variety of forms, as shown in the geyser cones and incrustations upon the surface and edges of the hot pools. These sinters form the brilliant white deposits found over large areas in all the geyser basins. Scorodite, realgar, orpiment, oxide of iron, wad, and other minerals occur under favorable conditions as deposits from hot waters at certain springs, each adding something of interest to the marvels of the Park.

It is these unrivalled hydrothermal manifestations, and their geological relations to the earlier volcanic eruptions, that have made the Yellowstone Park famous throughout the world, and have justly gained for it the appellation of the Wonderland of America.

Another characteristic feature of the Park, and one that adds more than anything else to the scenic charms of the plateau, are the singularly beautiful, deeply eroded canyons that carry the waters from this elevated region to the broad valleys below. They are all of comparatively modern origin, presenting all the phenomena of recent canyon cutting. Of all these picturesque gorges, the canyon of the Yellowstone stands preeminent in grandeur and sublimity of its scenery. Nearly all these gorges carry waterfalls of great beauty, each adding some special attraction to the charm of the place. Nearly twenty picturesque falls may be found within the Park.

Across the plateau lies the continental divide, separating the waters of the Atlantic from those of the Pacific. Entering the Park from the southeast corner it runs with an irregular course in a northwest direction, following along the summit of Two Ocean Plateau, the waters of the plateau draining to both oceans. The watershed follows the undulating low ridge between Shoshone and Yellowstone lakes, and, with a broad sweeping curve around the streams running into the latter lake, crosses Madison Plateau and leaves the Park a short distance south of Madison Canyon. Several large bodies of water form such characteristic features on both sides of this divide that the country has deservedly received the designation of the lake region of the Park.

About 85 per cent of the Park is forest-clad. The timber is essentially coniferous, with here and there a few small growths of aspen. Two-thirds of the trees belong to the black pine, *Pinus murrayana*, and on many of the gravelly, rhyolite ridges no other species is seen. It rarely attains any great size, but for the purpose of water protection, one of the objects for which the reservation is maintained, it meets every economic requirement.

ITINERARY OF THE YELLOWSTONE PARK.

By Arnold Hague.

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Cinnabar to Mammoth Hot Springs	7
Mammoth Hot Springs to Norris Geyser Basin	22
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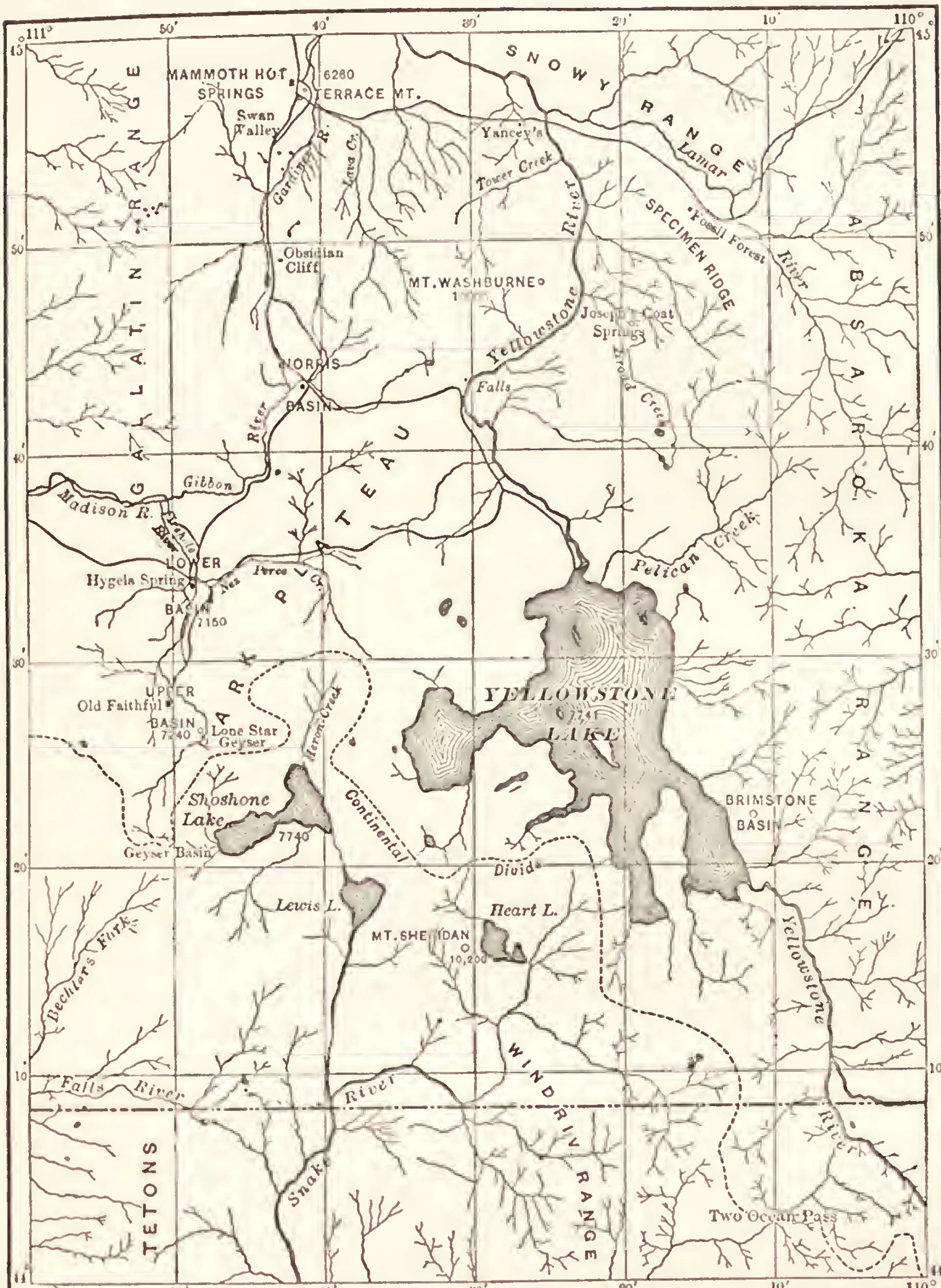
Yellowstone Falls to Mammoth Hot Springs	33
Mammoth Hot Springs to Cinnabar	7

At Cinnabar station the travelers leave the railway and continue their journey for the next few days in stages. The road follows the Yellowstone river to Gardiner, thence up the Gardiner river to the Mammoth Hot springs. The northern boundary of the Yellowstone Park passes east and west through the junction of the Yellowstone and Gardiner rivers. About one and one-half miles beyond, the boundary line between the States of Montana and Wyoming is crossed. Entering the Park the road follows the river, with the long spurs of Mount Evarts on the left and those of Sepulchre mountain on the right. Mount Evarts, which rises 2,000 feet above the stream, affords an excellent exposure of Middle Cretaceous sandstones and shales dipping away from the river. Leaving the river the road crosses an ancient travertine deposit, and ascending a steep hill reaches the Mammoth Hot Springs hotel, situated on the finest of the travertine terraces. Travelers generally reach the hotel about noon, and the remainder of the day is spent in examining the hot springs and terraces, and the geological features in the neighborhood. Several days might be spent here with profit, visiting objects of interest within a radius of 10 miles of the springs.

MAMMOTH HOT SPRINGS.

The Mammoth Hot Springs deposits consist entirely of travertine, derived from waters heavily charged with carbonate of lime. The total area covered by travertine is about two square miles, occupying a narrow valley lying between Terrace and Sepulchre mountains. A continuous deposit extends from the Gardiner river to the top of Terrace mountain, a vertical distance of nearly 1,400 feet, the width and depth of travertine depending upon the form of the original valley. The top of Terrace mountain lies about two miles back from the river. On the north side of the valley, Cretaceous and Jurassic rocks

may be seen rising abruptly from beneath the travertine which rests against them. A series of terraces extends all the way from the river to the top of the mountain, eight of which are well-defined benches



Scale. 1 inch—12 miles. **YELLOWSTONE NATIONAL PARK**

with more or less level floors and steep slopes facing the open valley. Seen from any commanding point of view, this series of terraces, inclosed within a mountain gorge suggests the terminal front of a

mountain glacier. The Hotel terrace is the broadest of all the terraces, with an area over 83 acres in extent. It is situated 500 feet above the river and from it most of the others are in full sight. All active springs are found either upon the Hotel terrace or upon those higher up the valley. The number of active springs may vary from year to year, some becoming extinct, while new vents are opened. The temperature of the springs ranges from 80° to 165° F., in all of which algæ have been found growing. This peculiar vegetation plays an important part in the formation of travertine by the secretion of lime, and much of the exquisite beauty of the springs and brilliancy of coloring is produced by these low forms of plant life.[43]

The principal objects of interest are the extinct springs, Liberty Cap and the Thumb, on the Hotel terrace, and such active springs as Pulpit Basins, Marble Basins, and the Blue spring, on Main terrace, and still higher Cleopatra's Bowl, Cupid's Cave, and the Orange spring. There are also innumerable small caves and fissures, each having special features of interest; some of the caves contain carbon dioxide in sufficient quantity to be dangerous to animal life. The largest active springs are centered on Main terrace, 8$\frac{3}{4}$ acres in extent and 250 feet above Hotel terrace. Beautiful clear pools abound, the largest of which is nearly 100 feet in diameter, with a temperature of 136° F. Blue spring on this terrace is perhaps the most interesting of all in its phenomena of travertine deposition. The building up of travertine in a series of small basins, one above the other, the delicacy of coloring from algous growth, and the overflow of hot water are admirably shown. The spring has a temperature of 165° F.

Over the greater part of the travertine area hot springs have long since ceased to flow, although they may break out anew at any time. Where they have long lain dormant, the spring deposits are now covered by a coniferous forest. In some instances the trees have been killed by fresh outflows of hot water, the dead and bleached trunks still standing with their roots buried in travertine.

Sepulchre mountain, to the northwest of Mammoth Hot springs, stands out boldly as a volcanic peak, on the northern boundary of the Park. It consists of flows of compact andesite and breccias stretching in long gentle slopes toward the Yellowstone and Gardiner rivers. These spurs exhibit a succession of ice-carved benches, the surface being strewn with glacial débris from the Gallatin Mountains.

Mount Evarts on the east and Terrace mountain on the west shut in the Mammoth Hot springs on two sides, the former by a bold wall rising abruptly above Gardiner river and the latter by long gentle slopes inclined toward the river. Facing the basin on the south rises a grand escarpment of volcanic rocks, the northern edge of the Park plateau, stretching from the head of Lava creek westward as far as

Bunsen peak. Terrace mountain is an outlying mass of the plateau, formed of rhyolite and capped at its northern end by travertine. The cliff on the southern end of the summit of Mount Evarts is a thin extension of the great rhyolite lava sheet, separated from the main mass by the erosion of Lava creek.

Within a few miles of the Mammoth Hot springs are several beautiful waterfalls, formed by the waters of the plateau leaping over walls of compact basalt in their descent to the lower country. Among them may be mentioned Osprey falls on the Gardiner river, and Undine falls on Lava creek, both of which are well worth a visit.

MAMMOTH HOT SPRINGS TO NORRIS BASIN.

Leaving the Mammoth Hot springs (6,250 feet), the road gradually ascends over rhyolitic rocks more or less covered by alluvium and glacial débris. On the west side of the road, just before reaching the Golden Gate, immense blocks of travertine may be seen piled up one upon the other in a confused mass in a manner at first difficult to understand. They are best explained by supposing them to have been thrown forward from Terrace mountain by some sudden earthquake shock which thrust the easily displaced rock from its original position down the side of the mountain.

At Golden Gate the road enters the picturesque gorge of Glen creek, which separates the plateau escarpment from Terrace mountain. At the upper end of this gorge the road enters upon the open grassy plain of Swan Lake valley (7,200 feet), a northern extension of the plateau. A narrow ridge of andesitic rocks—a spur of Sepulchre mountain—shuts in the valley on the west. Opposite Swan lake andesite gives way to rhyolite, which in turn is replaced by basalt, forming the extreme southern end of the ridge and falling away gradually to the level of the plain. This basalt, in thin flows, stretches across the valley, and its southern limit is sharply defined by the course of Gardiner river. The valley is strewn with glacial drift from the Gallatin mountains, and evidence of ice movement is everywhere to be seen, especially in low morainal ridges trending across the valley, which are shown in cross section by the wagon road. From Swan Lake valley a fine view is obtained of the Gallatin range to the west, extending all the way from Electric Peak (11,125 feet) to Mount Holmes (10,578 feet) a distance of 13 miles in an air line. Snow lies upon the higher summits well into midsummer.

Crossing Gardiner river, the road passes up the valley of Obsidian creek, the lower part of which is known as Willow park, a long strip of meadow land the borders of which are in great part covered with a luxuriant growth of willow, beyond which rise the stately pines of the plateau. The scenery now assumes a monotonous appearance, due

to the almost uniformly level character of the rhyolite ridges, through which the streams follow long straight valleys characteristic of this part of the Park. The rock is everywhere rhyolite, which fortunately exhibits a great variety of modifications. On the west side of the road, as it approaches Obsidian Cliff, there is a small exposure of columnar rhyolite.

Obsidian Cliff, on the east side of the stream, near the outlet of Beaver lake, is of more than ordinary interest to all tourists, but especially so to the geologist, on account of its peculiarities of structure and the development of spherulites and lithophysæ found in it. The cliff rises in nearly vertical walls from 150 to 200 feet above the stream. It has been formed by a surface flow breaking out and running over the rhyolite plateau, covering an area of about 10 square miles. The obsidian is a natural glass, the result of rapid cooling from a fused mass of highly acid lava, and has much the same chemical composition as the plateau rhyolite. On the surface, at the northern end of the cliff, it grades into pumice and lithoidal rhyolite. I am indebted to Mr. Joseph P. Iddings, who has made a careful study of Obsidian Cliff, for the following note:

The columnar structure at the southern end of the cliff is particularly well developed. The compact black obsidian passes into lithoidal rock northward along the face of the cliff, where various phases of crystallization may be studied in situ.

On the top of the plateau, to the east, the dense obsidian passes upward into white pumice, which has been more or less removed by glacial action. The fresh, unaltered condition of rock permits the mineralogical character of the crystallization to be observed in the utmost detail. The perfection of the lithophysæ and spherulites, and the richness of the microscopic spherulitic growths constitute its most important petrographical feature.

The lamination of the lithoidal portion of the mass and the general lamellar distribution of different kinds of structure, as well as of the gas bubbles in the vesicular and pumiceous parts of the sheet, furnish valuable evidence as to the agent most active in promoting the various kinds of crystallization in this and similar rhyolitic lavas. This agent was undoubtedly water-vapor.[12]

A short distance south of Obsidian Cliff lies Beaver lake, across which are several dams kept in repair by beavers who inhabit its waters. Since the rigid protection of game in the park the beaver are rapidly increasing in number, and several of their houses may be seen in the lake.

Shortly after passing Beaver lake the rhyolite begins to show the effects of hydrothermal action, and numerous areas of rock decomposition may be observed on both sides of the road.

Four miles south of Obsidian Cliff, Roaring mountain is passed. This is a bluff rising 500 feet above the road and one of the highest points on the lava ridge. It takes its name from the shrill, penetrating sound of the steam constantly escaping from one or more vents located near the summit, and on a calm day, or with a favorable wind, the

rushing of the steam through the narrow orifices can be distinctly heard from the wagon road. The mountain is one mass of altered rhyolite, whitened by long action of steam and acid vapors. The entire ridge, lying between the road and Solfatara creek to the east, is largely formed of these highly altered rhyolites. It is evident that this region was at one time a center of long continued and energetic thermal activity.

Beyond Twin Lakes the water drains southward to Gibbon river, and from here to Norris basin along the roadside at the base of the cliff there is a succession of steam vents, hot springs, and mud pots.

NORRIS BASIN.

This geyser basin (7,350 feet) occupies a depressed area on the east side of the Gibbon river, the waters of the basin draining toward the stream. Rhyolite ridges surround the basin, gradually rising on all sides toward the summit of the plateau. In many respects this basin is the most instructive of all, as the varied phenomena of thermal action in all its phases are more clearly shown here than elsewhere. All stages of rock decomposition and of deposition of sediments from hot waters may be seen and are easily accessible to the pedestrian within a short walk of the hotel.

The basin contains 14 geysers, which, although neither so grand nor impressive as those in the Lower and Upper Geyser basins, are, on account of the varied phenomena exhibited, quite as interesting to the geologist. Several of them are of quite recent origin, as is shown by the freshness of the rocks through which the steam issues and by the absence of sinter deposits. The Monarch is one of the most interesting of the group. It breaks out through a narrow vertical fissure, 20 feet long, in the rhyolite. Eruptions take place every four hours, the water being thrown into the air for 50 feet. Other interesting geysers are the Arsenic, Constant, Congress, Fearless, and Pearl. Owing to the great number of steam vents and active orifices, each with some characteristic feature of its own, the basin presents one of the most weird and desolate regions in the Park.

NORRIS BASIN TO LOWER GEYSER BASIN.

Shortly after leaving Norris basin the road crosses Gibbon meadows, a broad open plain which in places is almost impassable owing to the wet marshy nature of the bottom. The Gibbon river runs through the Meadows. The ditches constructed for drainage purposes along the roadside expose, underlying the meadow, a fine white earth several feet in thickness, largely composed of diatoms developed in the siliceous waters. Similar diatomaceous ooze is found in nearly all the

geyser basins, although seldom on so extensive a scale. Encircling the Meadows, at the base of the hills, are a number of local centers of thermal activity from which large quantities of hot siliceous waters drain into the basin.

A short distance off the road, on the east side of the Gibbon meadows, and easily reached by wagon, lie the Artists' Paint Pots. They consist of a number of small springs of hot water reaching the surface through brilliantly colored clays. These excessively fine clays are the products of rock decomposition by slow and long-continued processes, and the mineral matter held in suspension is the cause of the varied colors in the different pots. In the white pots the coloring matter has been leached out, leaving a pure white kaolin impalpable to the touch. The deep indian-red pots carry finely comminuted iron oxide, which, under favorable conditions, collects in certain springs. The hillsides are brilliant with decomposition products derived from rhyolite in various stages of alteration.

From the Meadows the road follows the Gibbon-river through Gibbon canyon, the imposing walls of which rise in sheer cliffs 1,000 feet above the stream. It is a grand exposure of rhyolite walls, exhibiting remarkable forms of rock erosion. The river makes a rapid descent, and at Gibbon falls, 80 feet high, flows over a fine example of obsidian worn smooth by the rushing waters. Along the base of the canyon walls, in close proximity to the river, steam vents and hot springs mark the course of thermal action. Beryl spring, on the west bank near the northern end of the canyon, is worthy of attention from the exquisite coloring of the constantly agitated water which has built up a delicate rim of sinter encircling the pool.

At Canyon creek the road leaves the Gibbon river and follows the ridge of rhyolite on the east side. A short distance below here, the Gibbon and Firehole unite to form the Madison, the latter stream being one of the main tributaries of the Missouri. From a commanding point on the road a distant view may be had of the Madison canyon, extending in an east and west line directly across the plateau. The precipitous walls on the north side of the canyon rise for 1,500 feet above the river. Madison plateau stretches as far as the eye can reach, without a break, beyond which both rhyolite and basaltic lavas extend westward over the great plains of Snake river.

From the same point of view, on a clear day, Mount Hayden, which is not only the culminating point in the Teton range, but the highest peak in this part of the Rocky Mountains, may be distinctly seen 60 miles to the south. Descending a steep ridge over rhyolitic gravels, the road comes out on the Firehole river, and after following the bank for two or three miles enters the Lower Geyser basin.

LOWER GEYSER BASIN.

The Lower Geyser basin is about three miles square and is the largest of the geyser areas. It is roughly rectangular in shape and at the junction of Firehole river with Nez Percé creek, the lowest point in the basin, has an altitude of 7,100 feet. The Firehole river coming in from the south runs in a northerly direction across the basin, receiving all the waters brought to the surface by the geysers and hot springs. Several tributaries of the river reach the basin from the plateau, and along these streams are a number of active hot-spring areas. Some of them situated along Sentinel creek and Nez Percé creek are among the most interesting in the basin. The Queen's Laundry, an immense hot spring on Sentinel creek, is well worth a visit.

The Lower Geyser basin contains innumerable hot springs, steam vents, paint pots, mud pots, and 17 geysers. The largest geyser in the basin and one of the finest in the park is the Great Fountain, situated in the extreme southern end of the basin, about one mile south of the hotel. It is in every way a typical geyser. The brilliant, deep blue pool of water measures over 100 feet in diameter, resting upon a broad circular sinter mound, which stands about three feet above the rhyolite base. The formation of siliceous sinter and the phenomena of geyser action are clearly shown here, while the exquisite beauty of the basin will ever place the geyser in the first rank. A large volume of water is thrown violently into the air to a height of 75 feet. The eruptive action lasts about 20 minutes.

The Fountain geyser is situated only 200 or 300 yards from the hotel, and plays fairly regularly three or four times a day. Instead of issuing from a cone or mound, the water is thrown out from a funnel-shaped basin.

A few steps from the Fountain are the famous Mammoth Paint Pots, similar to others seen throughout the Park, although on a much larger scale. The clay has a delicate blue color and the consistency of dilute porridge.

Other geysers of interest are the Surprise, Spray, and White Dome.

LOWER TO UPPER GEYSER BASIN.

The road, after leaving the hotel near the edge of the timber on the east side of the Lower Geyser basin, crosses the broad sinter plain, and, after reaching the Firehole, follows closely the bank of that stream to the extreme eastern end of the Upper Geyser basin.

From the junction of the Firehole and Nez Percé creeks, active and extinct hot springs may be seen all along the river bank or in close proximity to it, steam from fissures frequently rising within a few inches of running water and alongside of cold springs.

On the west side of the river, between the two large geyser basins, lies a small but interesting geyser region known as Midway basin. It is a dazzling white sinter plain, without tree or meadow, the only relief to the eye being enormous volumes of steam rising from hot lakes and cauldrons. This basin contains the Excelsior, the grandest and most imposing geyser, and Prismatic lake, a singularly beautiful sheet of water unsurpassed for brilliancy of color and exquisite beauty of its rim. Excelsior geyser throws an enormous column of water, the more powerful eruptions emitting a stream 250 feet into the air, measuring 20 feet in diameter at the base and breaking into a fan-shaped body above. It rises from a circular cauldron of boiling, steaming water, the level of which lies about 15 feet below the surface of the sinter plain. The cauldron wall affords an excellent opportunity for a study of sinter deposition. The amount of water thrown out during any violent explosion reaches many thousand barrels, which, pouring over the edge of the cauldron, runs rapidly across the sloping plain and down the banks of the river into the stream below. The level of the Firehole river is frequently raised several inches, the water showing a marked increase in temperature for a long distance below the geyser. Frequently large blocks of sinter are hurled violently into the air by the force of the explosion.

The bluff on the east side of the Firehole river, opposite Excelsior geyser, is rhyolitic pearlite, and from the top of the cliff, on a clear day and the wind westward, Prismatic lake may be seen to great advantage.

From Midway basin the road passes a number of hot springs, but none of special interest until reaching the Sapphire group, situated on the west side of the Firehole. It contains a number of small geysers, each exhibiting some novel feature of thermal action peculiar to itself. Sapphire pool, a large circular basin raised slightly above the sinter plain, has scarcely any rival among the marvelous springs along the Firehole. It closely resembles the Great Fountain in the character of its sinter deposits and overflow basin. The water is of the deepest blue and the temperature always stands near the point of ebullition. Near by are the Jewel, Silver Globe, and Avoca.

For a mile along the river, before reaching the Upper Geyser basin proper, there is a line of hot springs and geysers, indicating a great amount of thermal action along the valley. Among the most important may be mentioned the Cauliflower, Gem, Artemisia, and Morning Glory. A good illustration of the difficulty which may sometime arise in distinguishing a hot spring from a geyser is seen in the case of the Artemisia, which for a long time was supposed to be a quiet pool, but in recent years has exhibited all the phenomena of explosive geyser action.

UPPER GEYSER BASIN.

At the Riverside geyser the road crosses the Firehole river by a bridge, which is generally regarded as marking the entrance to the Upper Geyser basin. The basin measures about two and one-half miles in length and one and one-quarter miles in width, and contains the greatest number and, with the exception of the Excelsior, the largest geysers in the park. At the Grand geyser, a central point, the elevation is 7,200 feet above sea level. Like the Norris and Lower Geyser basins it occupies a depressed area in the rhyolite lavas, with ridges rising more or less abruptly on all sides, the Madison plateau on the west presenting a bold escarpment. The Firehole river extends the entire length of the basin, and with its tributaries drains the region. The basin lies within 5 miles of the continental water-shed which separates the Atlantic from the Pacific drainage. The lowest passes between the two are not more than 800 feet above the basin, and the line of the Continental Divide makes a sharp bend and loop to the southeast in order to inclose the drainage area of the Firehole on the Atlantic side.

There are between 45 and 50 geysers in the Upper basin, and nine of them may be regarded as geysers of the first order. The Giant, Giantess, Grand, Splendid, Grotto, Castle, Beehive, Oblong, and Old Faithful are found within a few hundred yards of the river and within easy walking distance from the hotel, which is situated near Old Faithful. While the geysers present much in common, each offers distinctive features in the display of the water thrown out, the quantity discharged, the duration of explosive energy, and in the intervals between eruptions. The height of the column of water in these large geysers varies from 60 to 250 feet. Old Faithful is the most regular, with intervals averaging sixty-five minutes, throwing a column of water varying from 90 to 150 feet. The Giantess issues from a deep, funnel-shaped pool. The Giant has built up a sinter cone 10 feet in height. The Castle breaks out from the top of a series of sinter terraces. The Grand presents a quiet, shallow basin on the level with the sinter plain. The Splendid issues from an unpretending pool not unlike hundreds of hot springs in the park. Black Sand and Emerald springs afford excellent opportunities for a study of algous growths in hot waters. There is a most interesting group of springs and geysers, seldom seen by tourists but well worth a visit, on Iron creek, a tributary of the Firehole.

Plate 11 represents Old Faithful in action. It is a fine exhibition of the geyser, which is seen to the best advantage on a calm day, the absence of all wind permitting the water to fall freely in a perpendicular column broken up into graceful arrow-shaped bodies. The water column

OLD FAITHFUL IN ACTION.

is surrounded on all sides by steam and dense vapor. The broad circular mound surrounding the orifice of the geyser is built up by a series of low sinter terraces, many of them holding pools into which the descending water falls. The great regularity of Old Faithful makes it an object of intense interest to tourists and one seen by all visitors to the Park.

LOWER GEYSER BASIN TO YELLOWSTONE LAKE.

Returning to the Lower Geyser basin the road turns off to the east and follows Nez Pereé valley for nearly 10 miles. On entering the valley the Morning Mist group of springs is seen on the south side of the road, skirting the base of the hills and extending up on to the ridge. The hillsides are covered with small springs and steam vents, concealed by timber during the greater part of the day, but in early morning presenting a picturesque appearance by the numerous columns of steam which rise through the dark green forest. The Nez Pereé is characteristic of the larger valleys of the region, and evidences of its former occupation by ice may be seen on the long monotonous lava ridges.

A steep ascent of 900 feet leads up to the top of the central plateau, and from an opening in the timber on the edge of a steep cliff a magnificent view may be had looking backward down the valley and out over the geyser basins and Madison plateau beyond. The road then crosses a treeless portion of the plateau over pearlite, obsidian, and various modifications of glassy rhyolite.

The Highland Springs area lies just south of the road on the very top of the plateau. It is a region desolate beyond description, but of great interest in a study of the action of acid waters upon siliceous lavas. The waters of Alum creek, which rise in the Highland springs, have a very obnoxious and astringent taste.

Leaving the plateau, a descent of 200 or 300 feet brings us out into Hayden valley, a broad, shallow depression in the rhyolite. The underlying rocks are modifications of glassy rhyolite, over which occur Tertiary lake beds and morainal material of the glacial period.

After skirting the southern end of the valley along the edge of the timber, the road turns southward, following Yellowstone river for eight miles to the Lake. Shortly after leaving the valley a hot spring area several acres in extent is reached, extending from the banks of the river up on to the slopes of the ridge. It is quite like other areas in most of its thermal manifestations, but the Mud geyser and the Mud volcano have attracted more than ordinary interest. The Mud geyser behaves like an ordinary geyser, except that instead of ejecting clear water it contains a mixture of clay and water, throwing the slimy material from 20 to 30 feet in the air. The Mud volcano is situated a short distance from the geyser on the steep side of a hill. A caldron 20 feet in depth

with steep slopes suggests a volcano, at the bottom of which are blackish gra, slimes, not unlike the mud thrown out from many volcanoes. The con. y all about is strewn with clay pellets, showing that occasional e -iosive action throws out the mud for considerable distances, although in most instances the force is only sufficient to raise the clay to the rim of the caldron. Six miles from the Mud Volcano the hotel is reached, near the outlet of the lake.

YELLOWSTONE LAKE.

Yellowstone lake has an altitude of 7,741 feet above sea level, is over 20 miles in length and of very irregular width, reaching 15 miles across its broadest expansion. It embraces an area of about 140 square miles, and it requires a ride of 100 miles along its shore to complete the circuit. Rhyolites encircle the shores of the lake on all sides. On the opposite, or eastern side, the Absaroka range rises as a rugged mass of mountains, mainly composed of andesitic and basaltic rocks, the greater part of them being agglomerates and breccias. Similar rocks form the Promontory mountains projecting into the lake from the south. Flat Mountain to the south and west of the Promontory is a broad inclined table of rhyolite. Mount Sheridan, which stands out boldly to the southwest, is an extinct volcano from whose summits and sides have poured forth vast accumulations of rhyolitic lavas. Surrounding the lake on all sides and extending back from the shore are broad benches of sand and gravel, the highest of which is distinctly marked at 150 feet above the present level of the lake. This ancient lake bench may be traced along the cliffs in Hayden valley. On the beach along the west shore may be seen andesitic boulders from the Absaroka range that have been transported by ice across the lake in large quantities. On the arrival of tourists a small steamer makes a trip around the lake, giving an opportunity for obtaining fine views of the Absaroka range, Mount Sheridan, the islands, and the imposing valley of the Upper Yellowstone.

YELLOWSTONE LAKE TO YELLOWSTONE FALLS.

In order to visit the Canyon and Falls of the Yellowstone the route follows down the river and across Hayden Valley in a northwest direction over an undulating grassy plain. The first object of special interest to the visitor is Crater hills, where there is a remarkable grouping of steam vents and solfataras. These isolated hills, rising above the valley for 150 to 200 feet, are covered from base to summit with hundreds of steam vents, from which issue acid vapors depositing the most delicate sulphur crystals in innumerable cavities and fissures. Only a slight flow of water is visible at the surface, but at the base

of the largest hill and close to the roadside lies Chrome spring, a constantly boiling pool of the most delicate sulphur-yellow tint. Two miles beyond Crater hills, Alum creek is again crossed just before it empties into the Yellowstone, and a short distance northward the road leaves Hayden valley and follows the west bank of the Yellowstone for three miles along picturesque rapids inclosed between walls of rhyolite.

YELLOWSTONE CANYON AND FALLS.

The Grand Canyon hotel, on the west side of the river, is situated on a glacial bench about one-quarter of a mile back from the canyon and the Lower falls of the Yellowstone. The Yellowstone canyon trends to the north and northeast, curving around an east spur of Mount Washburne, its length from the upper falls to Junction Butte being about 18 miles. At the Lower falls the walls of the canyon measure 700 feet, and five miles beyond, 1,000 feet, the width of the canyon varying from one-quarter to three-quarters of a mile. Rhyolite forms the canyon walls which are more or less decomposed by hydrothermal action, their color being due to various conditions of oxidation of the iron. Where the greatest decomposition has taken place the iron has been leached out, leaving a white kaolin-like material. A few hot springs may be seen steaming in different parts of the canyon, showing that thermal action is not yet extinct. The gaily colored walls extend about five miles beyond the Lower falls, but below this the rock is dark colored, still fresh and unaltered. The Lower falls are 310 feet in height, and may be seen to the greatest advantage from Inspiration Point, one of the cliffs which overlook the canyon below the Falls. Lookout Point furnishes another excellent point of view.

In following the bridle path along the brink of the canyon one should see the massive glacial granite boulder (Fig. 15), near where the side path leaves for Inspiration Point.

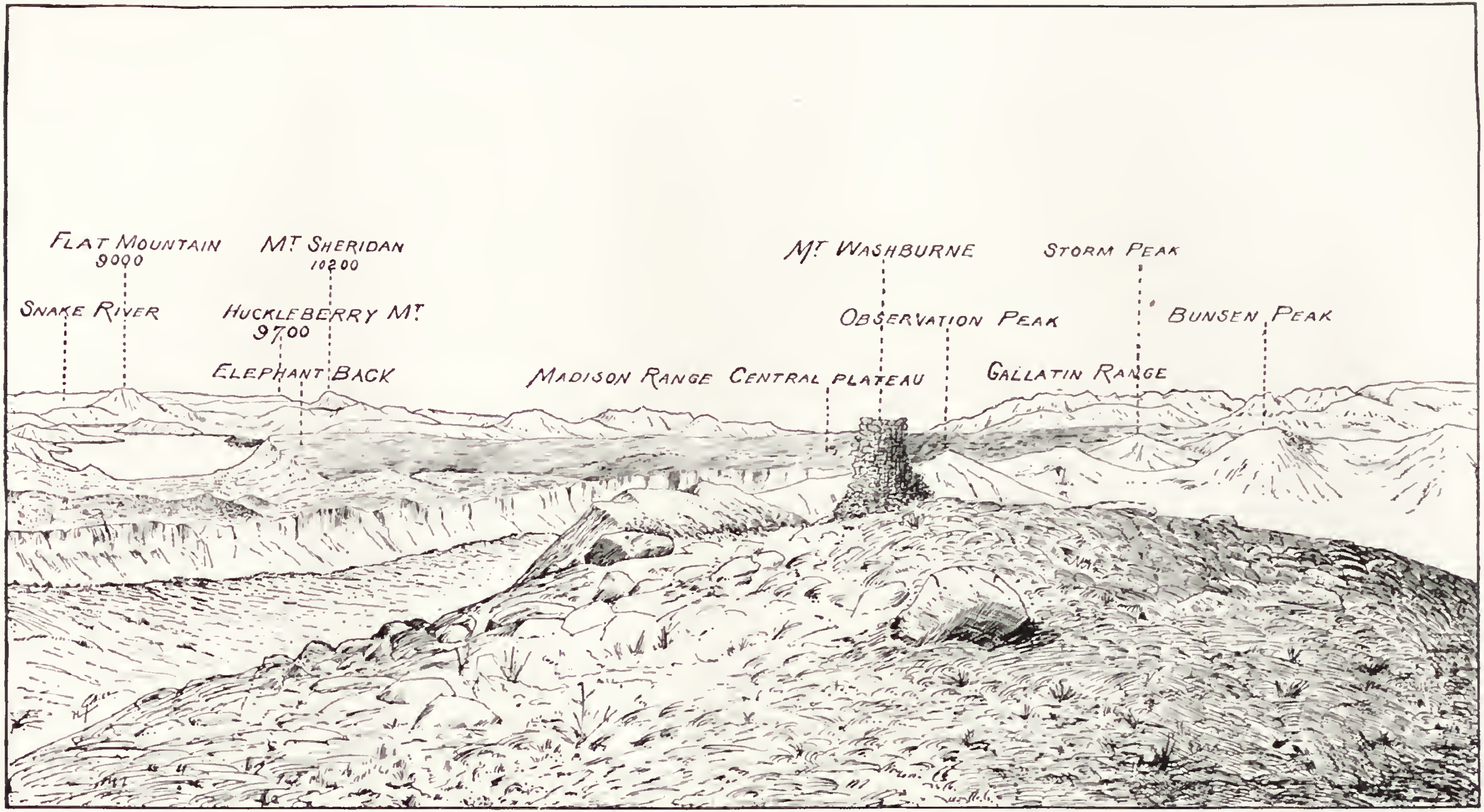
One-half mile above the Lower falls are the Upper falls, 110 feet in height. Here the rhyolite is undecomposed, mostly glassy, and more or less spherulitic, and is well exposed on Cascade creek.

From the hotel an expedition may be made to the summit of Mount Washburne which on a clear day commands a view over the Park and the Absaroka range.

YELLOWSTONE FALLS TO MAMMOTH HOT SPRINGS.

Leaving the hotel at the Falls the road climbs up a steep ascent to the top of Solfatara plateau, an extension northward of Central plateau, which was crossed when going from the head of Nez Percé Creek to Hayden Valley. The thermal action seen on Solfatara plateau is in every way similar to that observed at Highland springs, but is by no

SKETCH OF YELLOWSTONE CANYON AND INSPIRATION POINT.



PANORAMA FROM SUMMIT OF MOUNT WASHBURNE—LOOKING SOUTH.

means displayed on so grand a scale. The summit here has an elevation of 8,100 feet, and is for the most part formed of various modifications of glassy rhyolite. The road with a gradual descent follows down the Gibbon River valley through a pine forest characteristic of the Park. At the picturesque Virginia cascade, on the Gibbon, the rock exhibits most interesting forms of erosion in the easily crumbling rhyolite. Three miles beyond the Virginia cascade, Norris basin is reached, and from here to Mammoth Hot springs the route follows the same road traversed upon entering the Park.

Plates III and IV are from sketches made during the excursion by MM. Eysséric and Golliez of the visiting geologists.

THE FORMATION OF HOT SPRING DEPOSITS.[43]

By Walter H. Weed.

Travertine.—The travertine deposits of the Mammoth Hot springs form one of the most interesting features of the region. Covering two square miles and attaining a thickness in places of 250 feet, the deposits have few equals in size, while the beauty of the terraced basins, the brightly tinted slopes covered by the steaming waters, and the varied views presented can not fail to impress every observer.

With the exception of the Hot River, all the active springs now issue from the terraces above the hotel; elsewhere the older deposits are quite generally covered by a forest growth of pines and spruces. In wandering about the springs one is sure to notice the brightly tinted basins surrounding the vents, with the red or orange colors of the slopes overflowed by the hot waters. These colors are due, not to mineral matter, but to the presence of algæ growing in the hot waters and frequently so covered by carbonate of lime as to be scarcely recognizable. These plants take a most important part in the formation of the travertine deposits, and in fact it is their presence that has caused the great beauty of the deposits. The varied tints are due to a different color of the algæ at varying temperatures, examples of which are seen in the beautiful mosaic of basins about the vents of the Blue springs on the Main terrace.

The fact that these deposits of travertine are mainly due to plant life has been fully proven by a careful study of the old deposits and of those now forming. This action of algæ was first observed by Ferd. Cohn at Carlsbad and other European localities, and the study of the Yellowstone deposits simply extends and confirms his theory. The proof is readily available at the Mammoth Hot Springs, and, though other causes cooperate to produce a separation and deposition of the carbonate of lime from the hot waters, the plant life is seen to be the chief factor in the production of the many varieties of calc sinter found about the springs. In the case of the fibrous tufa forming the fan-shaped masses found about many of the vents, an examination with a lens shows that the fibers are simply encrusted algæ threads. The rippled surface of the deposits covered by the overflow of the larger springs shows a furry covering of orange-colored algæ, the upright threads extending down into the mass. In both these cases the algæ filaments serve as a nucleus for encrustation, besides absorbing carbon dioxide and thus causing the separation of lime carbonate. The

masses of gelatinous algæ, often several inches thick and forming mat-like coverings in the sluggish overflow channels, show the action of plant life most clearly. The successive layers of membrane-like material carry minute little crystals and stellate accretions scattered about in the plant tissue. These grow into small pellets that uniting together produce firm layers. Thin laminæ of carbonate of lime also form between the membranes, and a compact deposit of travertine results from a combination of the two.

Siliceous sinter—The hot springs and geysers of the Yellowstone are surrounded by large areas of siliceous sinter that often entirely cover the floor of the geyser basins. About the spouting vents this material has been built up into mounds and cones of unique forms and great beauty. The more quiet pools have built up more or less regular mounds of white sinter which are in places as much as 20 feet in height above the surrounding level. Besides these deposits, the alkaline waters of the geyser regions have left deposits of silica wherever they have flowed, and many square miles within the park are covered by white and glistening deposit of this material.

Until the Yellowstone deposits were studied it was the generally accepted theory that the geyser waters reached the surface heavily charged with silica, which by relief of pressure, by cooling, and by evaporation was precipitated out and deposited by the waters. Observation of the natural conditions under which the Yellowstone deposits are forming, together with experiments and a study of the chemical analyses of the geyser waters, showed that the silica brought to the surface by the geyser waters was not separated out and deposited by the first two causes, but that deposits are formed about the geysers and the margins of springs by evaporation, producing a true *geyserite.* A new mode of deposition was then recognized, namely, the separation of silica by plant life, by the algæ that are abundant in the hot waters of the region. It is by this agency that by far the largest part of the sinter deposits of the region have been formed.

This algous vegetation is sure to be observed by every visitor to the region. Its varied tints of pink, yellow, orange, red, brown, and green adorn the slopes of geyser cones, flush the white silica of the little basins with their tints, and mark the waterways with their brilliant colors. It is ever present where the temperature does not exceed 185° F., often lining the great bowls of the cooler springs and *laugs* with leathery sheets of brown or green. Where a constant overflow prevails, the channel is often filled by a vigorous growth in which an algæ mat is formed having the consistency of a firm jelly, and most beautifully colored. In whatever form it is found, and no matter how brillantly tinted, this algous material if removed from the water and dried in the hot sun of the region rapidly loses its color, shrinks in

size and, becomes an opaque white mass of silica, whose weight is not one per cent of its former state. Chemical analysis shows this dried material to be silica and water, viz:

SiO_2	93.37
H_2O	4.17
Organic matter	1.50

Experiments showed the writer that the growing algæ form a jelly of hydrous silica; it is of this material that the algæ filaments are formed, and the algæ slime of other waters is here a hydrous silica binding the threads together. The nature of this separation may be seen under the microscope, though the fresh hydrous silica is difficult to study, and the dried material becomes opaque. In most cases the glassy rods can be readily distinguished and the inclosing paste usually shows globules and pellets of the dehydrated silica.

The process of sinter formation is best illustrated, and its importance most apt to be appreciated, by an examination of an area covered by a large and constant overflow, such as that from the Black Sand whose connected overflow pools are known as Specimen lake. Here the algæ growing in the waters rapidly choke up the channel and cause the main supply to be diverted. Basins are formed by the algous growths, and in them pillars grow up from the bottom that are often a foot in height. These increasing in number finally fill the pool, their tops reaching the surface coalesce and roof over the basin until the waters, becoming choked, seek other outlets. The gradual lessening of this supply of water causes the final death of the algæ. In the cool waters that fill the space between the pillars the hydrous silica begins to harden. Aided by the acids of the decomposing vegetable matter this process is quite rapid, and more silica is separated from the cold water to form a coral-like coating, and finally the former soft algous jelly becomes a hard and firm rock. Eventually diversion of the hot waters builds up another growth upon the old one and thus the channel, swinging around from side to side, successively forms new basins, new growths, and new deposits of silica.

Every step of this process has been patiently studied for many years. In the majority of cases it is less easy to recognize than at Specimen lake. In the channels that carry off the water ejected from Old Faithful geyser, for instance, a different species of algæ from that building up the deposits of Specimen lake forms a velvety furze upon the channel floor. Its color is a brilliant orange to a cedar-red or dark seal-brown, depending upon the temperature. This species, identified as *Calothrix* by Wolle, forms a delicately fibrous but close-grained sinter, quite unlike the coralline masses of Specimen lake. The tangled silky skeins seen floating in the overflow of the Giantess and other geysers,

and abundant as a thin orange-colored mat about the great Prismatic Spring, is a *Leptothrix* and produces a thatch-like or straw-like form of sinter.

A collection of these hot water algæ made by the writer is being studied by Prof. W. G. Farlow, of Harvard University.

The importance of these plant growths in building up sinter deposits may be realized when it is stated that in the walls of the great Excelsior geyser a section of 15 feet in thickness is exposed, of which over 12 feet is recognized as clearly and undoubtedly of algous formation, and the remainder of cemented fragments of weathered sinter. Even where the deposit does not reveal its origin by its structure, as is the case in the glassy compact sinter whose thin layers compose the platform about the Giant geyser, it is probable, judging from present conditions, that it is but an algous sinter altered by the long continued action of steam and percolating waters.

When the varied conditions of life and of evaporation are observed, it becomes at once apparent that any attempt to estimate the age of a geyser by the thickness of its deposits is a most difficult problem and a wholly unreliable foundation for other than comparative statements. Sinter formed by evaporation is produced very slowly under the most favorable conditions at the Firehole Geyser basins; one-twentieth of an inch a year is the maximum. Sinter formed by plant life may attain a thickness of eight inches a year in limited areas.

In general the sinters produced in these two modes may be readily distinguished by their physical structure. In chemical composition they are so alike that they cannot be separated.

Of less importance, because of its greater rarity, is the production of a siliceous deposit by a moss, *Hypnum aduncum*, observed at the Upper Geyser basin and at the Madison or Terrace springs. The moss grows only in the cooled waters that have already had considerable silica extracted while hot by the algous growths mentioned, but the moss growing in the cold waters is rapidly incrusted, in fact appears to build its structure largely of silica, and the resulting deposits cover several acres at each locality.

Diatom beds are common throughout the Park, but the deposits now forming are all in cool marshes supplied by hot spring waters. The resulting diatom earth, beds of which are sometimes six feet thick, generally contains more or less glassy silica separated from the waters by decomposing vegetable matter.

LIVINGSTON TO THE SNAKE PLAINS.

ITINERARY.

Station.	Distance.		Elevation.	
	Miles.	Kilometers.	Feet.	Meters
Livingston	0	....	4,487	1,368
Coal Spur	5	8	4,735	1,443
Hoppers	9	14	5,175	1,577
Muir	12	19	5,500	1,676
Tunnel	....	....	5,565	1,696
Sum. above tunnel	....	....	5,835	1,778
West End	14	23	5,540	1,689
Timberline	....	....	5,500	1,676
Mountainside	16	26	5,275	1,608
Fort Ellis	22	35	4,860	1,481
Bozeman	25	41	4,752	1,448
Storey	30	48	....	....
Belgrade	35	56	4,435	1,352
Central Park	41	66	....	....
Moreland	45	72	4,240	1,292
Logan	49	79	4,094	1,248
Three Forks	55	89	4,053	1,236

Station.	Distance.		Elevation.	
	Miles.	Kilometers.	Feet.	Meters.
Willow Creek	....	....	4,132	1,259
Sappington	68	109	4,178	1,273
Whitehall	87	140	4,343	1,324
Pipestone	94	151	4,690	1,429
Homestake	110	177	6,310	1,923
Homestake Tunnel	....	....	6,380	1,945
Sum. above tunnel	....	....	6,435	1,961
Butte[1]	120	193	5,570	1,698
Silver Bow	127	204	5,344	1,629
Melrose	159	256	....	....
Dillon	189	304	....	....
Beaver Canyon	265	426	6,025	1,836
Eagle Rock	332	534	....	....
Ross Fork	371	597	....	....
Pocatello	383	616	4,468	1,362

[1] Population, 10,723.

[By Walter H. Weed.]

At **Livingston** the railroad leaves the valley of the Yellowstone and passes due west up the valley of Billman Creek over Livingston beds, whose somber sandstones form the ridges on either side. At **Coal Spur** a branch line runs up Coke creek to the mines and ovens of Cokedale, where the Laramie coal seams are extensively worked,[44] a place where the relations of the Laramie and underlying Cretaceous to the Livingston beds are splendidly exposed. A dike of analcite basalt may be seen cutting the Livingston beds in a hill north of the railroad, a short distance beyond **Coal Spur**. From this point westward the ascent is very steep, 1,000 feet (305 m.) in 12 miles (18 km.), to the Muir tunnel, by which the railroad crosses the divide between the waters of the Yellowstone and the Missouri. Emerging from the tunnel, cut through the Livingston rocks, the railroad enters a mountain valley, passing the station of **Timberline**, where a narrow-gauge road runs to coal mines in Laramie rocks, two miles to the southward, that supply

the railroad with fuel. The coal-bearing rocks are seen at **Mountainside**, where the coals are also mined. West of here the road enters a narrow gorge known as Rocky canyon, cut across a sharply folded anticline pitching steeply to the north. The various formations of the Cretaceous are seen passing up the hillside to the north and, together with the Jurassic, curving around the massive limestones of the Carboniferous. The latter rocks form the picturesque pinnacles and towers of the central portion of the canyon. A little beyond, the Mesozoic strata are again seen, their sandstone beds curving about the Carboniferous in sharp flexures. The ridge cut through by Rocky canyon connects the Gallatin range to the south with the uplift of the Bridger mountains to the north, and is really a low part of the Front range of the Rocky Mountains, which is here broken down into a number of low uplifts arranged en échelon. The valleys are usually eroded in the soft Cretaceous shales; the ridges show the resistant limestones of the Carboniferous.

Leaving Rocky canyon the road enters the broad intermountain basin known as the Gallatin valley. Immediately north of the railroad the bluffs of the East Gallatin river show fine exposures of Neocene lake beds, the deposits here being conglomerates and coarse sandstones dipping at an angle of 3° to the northward. **Fort Ellis**, an abandoned military post, is built upon these lake beds that form the gently sloping table-land southward, beyond which the peak of Mount Ellis, formed of Carboniferous limestones, is seen.

[By Dr. A. C. Peale.]

Between **Bozeman** and **Central Park** the road passes over the alluvial valley of the Gallatin river. On the east side of this valley is the Bridger range, in which the nearest foothills are composed of gneisses. The portion of the Bridger range in sight from the railroad is a monocline, mainly of Paleozoic rocks, Carboniferous limestones forming the crest line, with Archean gneisses on the west. At the south end of the range the beds are overturned, the Cambrian, Devonian, and Carboniferous beds inclining to the westward, with the older beds on top dipping under the gneisses.

Bridger peak is the prominent point at this end of the range, while farther north Ross peak, although not the highest, is the most rugged prominent mountain seen from the railroad. South of the valley the Gallatin mountains are seen. They are composed mainly of gneisses and eruptive rocks. The most prominent peak, almost due south of **Bozeman**, is Mount Blackmore, which is composed of andesite, while farther to the west is the gneissic Gallatin peak.

The Gallatin valley is one of the old lake basins, of which a large

number are found in Montana. Its deposits were largely derived from showers of volcanic dust, which, falling into the quiet waters of the lake, were arranged in beds of very pure dust some 20 feet (6 m.) in thickness. Above these is a very considerable thickness of beds, evidently made up from the same material, which was washed into the lake from the shores and surrounding country and rearranged in beds of a rusty color.

At **Central Park** the railroad crosses the Gallatin river, whose head-branches have their source in the northwestern corner of the Yellowstone National Park.

From **Central Park** to **Logan** alluvium and Quaternary gravels, resting on lake beds, are passed over. As **Logan** is approached very good exposures of the Paleozoic and Algonkian beds are seen across the Gallatin river on the right, and the road passes through a cut in the former just before reaching **Logan**. Immediately opposite **Logan**, on the north side of the Gallatin river, there is a fine exposure of Cambrian, Devonian, and Carboniferous limestones in the bluffs that rise from the water's edge.

A few outcrops of the Paleozoic are noted on the left side, but the road soon comes out on the lake beds after leaving the Gallatin river below **Logan**. These beds are also well shown bordering the east side of Madison River valley just before **Three Forks** station is reached. They also show, in the distance to the south, between **Three Forks** and **Willow creek**. The Madison river is crossed just before the **Three Forks** station is reached. The Three Forks valley, at the lower end of which the Gallatin, Madison, and Jefferson rivers unite to form the Missouri river, is one of the most interesting geographical points in Montana. These streams were named by Lewis and Clarke, who first saw this valley in July, 1805, on their way to the Columbia river and the Pacific coast.

On the northwest or right side of the Jefferson river above **Three Forks** the hills are mainly of Cambrian, Devonian, and Carboniferous, the Algonkian beds forming the lower foothills farther up the river.

A short distance above **Willow creek** the road passes through a canyon, almost two miles in length, which the Jefferson river has cut through Carboniferous limestones. At the entrance to this canyon, on the north side of the river, stands a butte of basalt.

From the canyon the road comes out into the alluvial valley of the Jefferson, in which lies **Sappington** station. On the left (south) the hills or mountains are mainly of Carboniferous rocks. On the right (north) the nearest small ridges are of Jura, Trias, and Cretaceous. Above **Sappington** the Jefferson river is crossed and the road enters a second canyon cut in upper Carboniferous and Jura-Trias rocks, from which it emerges into a narrow valley in which the rocks are of Creta-

ceous age. These Cretaceous beds on the right (north) are faulted down against very somber-colored beds of Algonkian age. The hills on the left (south) are of Carboniferous, Jura, Trias, and Cretaceous. At the upper end of the valley the Cretaceous is faulted down against the Carboniferous, and the fault line is crossed by the road as it enters a third canyon, which is mainly in Carboniferous.

On the south side of this canyon placer-mining operations are carried on; the flume which conducts water for washing the gravels can be traced on the side of the hills for many miles, cutting through the rocks by tunnels in several places. A second fault-line is crossed a short time before the canyon is left, by which Carboniferous rocks are brought down against the Algonkian. The somber greenish beds of the latter are well shown on the right just before the Boulder river is crossed. Beyond, the road is located on a broad island in the Jefferson river, after leaving which the valley of Big Pipestone creek is followed. Here Pliocene lake beds rest upon granitic and eruptive rocks. As the road is followed a short distance above **Pipestone** springs it leaves the lake beds and comes out on a body of eruptive rock (porphyrite?) in which there are several cuts. This rock is in contact with the granite which occupies all the country in the vicinity of **Homestake** tunnel. From the tunnel to Butte everything is granitic.

[By S. F. Emmons.]

The granite hills form the divide or watershed between streams flowing into the Atlantic Ocean on the one side and the Pacific Ocean on the other. The age of these granites is not definitely known, but they are of eruptive origin and probably pre-Paleozoic. Having left behind the various valleys tributary to the Missouri river, the railroad now descends into the valley of Silverbow creek, which is one of the southeastern sources of Clarkes Fork of the Columbia river.

The interior portion of Montana was early discovered to contain the precious metals; rich placer gravels, from which great quantities of gold have been washed out, abounding in its valleys. They are still worked here and there, but their greatest production was in the decade 1860–1870. In the last two decades deep-mining has been steadily increasing, and has developed many famous mines, such as the Granite Mountain, Drumlummond, and others, which have paid millions in dividends to their fortunate owners.

Butte City,[45] the most important mining center of Montana, had a population in 1890 of 10,723, an increase of 218 per cent over that of 1880. Actual mining upon the silver and copper lodes which constitute its present wealth may be said to have commenced in 1875, though gold had been extracted from the placer sands of the neighboring valleys

since 1864, when the town was first founded. The earliest large mining operations were in the silver mines; the Alice, Moulton, and Lexington mines being the most prominent. The latter was purchased in 1881 by the "Société Anonyme des mines de Lexington," of Paris, France. During the last decade the copper mines have gradually increased in importance, and within the past few years the value of the copper produced has far exceeded that of silver. The production for the year 1890 was:

	Kilograms.	Value.
Gold, 25,704 ounces	800	$513,316
Silver, 7,500,000 ounces	233,264	9,696,750
Copper, 112,700,000 pounds	51,117,204	16,623,250

The city is situated on the southern slope of rounded granite hills, included within the angle of Silverbow creek as it flows first south and then west. It lies just east of a round conical hill, known as the "Butte," from which it takes its name. The greater part of the silver and copper mines lie in the hills back of and north of the city and to the east of the Butte, but a few important silver mines, notably the Bluebird and the Nettie, are situated a few miles to the westward, beyond the Butte.

Of reduction works for extracting the metals from their ores, the stamp mills are generally located on the hills near the mines, while the several smelting works lie in the valley of Silverbow creek. The smelting works of the largest copper mine, the Anaconda, are situated 27 miles (43 km.) to the northwest, where a town of the same name, of several thousand inhabitants, has been built around them, which is connected with the mines by a railroad.

The geological formation of the district is almost entirely of granite and rhyolite. There are two varieties of granite. The most widespread variety, which forms the country rock of the mines around the city and to the east of "the Butte," is an unusually basic rock, carrying a relatively large proportion of plagioclase feldspar; its basic minerals are mica, hornblende, and augite, and much of the hornblende appears to be only a paramorphic alteration of augite. The other granite occurs to the west of "the Butte" and forms the principal country rock of the Bluebird, Nettie, and other mines. It is a light-colored rock and consists almost exclusively of quartz and orthoclase feldspar, with a few minute grains of biotite. At its contact with the Butte granite it is found to send veins into it and include fragments of it, and is hence assumed to be of later age. The Butte itself consists of rhyolite, a fine-grained, granular rock consisting of quartz, sanidine,

and mica in a subordinate ground mass. This is evidently a later eruption, and sends out tongues or dike-like masses into the surrounding granite, which are not always visible on the surface but are disclosed in the deep drifts of the mines. Rhyolite of the typical banded variety also forms a series of low ridges about 5 miles (8 km.) west of Butte.

The ore deposits of the district occur in a series of veins in the granites, standing nearly vertical and having a general east and west trend. None so far as known have been found in the rhyolite. These veins are rock fractures produced by dynamic force and show evidence of a faulting movement in striated surfaces and zones of broken or crushed country rock, but have comparatively little selvage matter or clay walls. Each great mine consists as a rule of several parallel fractures or fissures, with minor cross-courses or fractures nearly at right angles with the main fissures; these sometimes appear to fault them, but it is by no means certain that they are later fractures. The ore is largely a replacement of the country rock from the original fissures outwards, it being often possible to trace a gradual transition from solid ore, through partially altered, into entirely unaltered granite, with no defined plane of demarcation or wall. In the silver mines the ore body or vein matter is often six to eight feet wide. In the copper mines much greater thicknesses of solid copper glance (chalcocite), sometimes 20 to 30 feet (6 to 9 m.) wide, are found.

The most common minerals in the silver mines are pyrite, sphalerite or zincblende, galena, and sulphides of silver, with manganese in the form of rhodocrosite or rhodonite, and little or no copper. Gold forms an important value in some ores, but it is rarely visible.

In the copper mines chalcocite, chalcopyrite, bornite, and enargite are the prevailing valuable minerals, but zincblende and the manganese minerals are almost entirely absent. Quartz is the general gangue material, and has apparently been derived by lateral secretion from the adjoining granites. Barite and fluorspar are also found. The oxidation of the manganese minerals, which form a remarkably regular constituent in the silver mines, produces very prominent outcrops or gossans, stained by the black oxide of manganese.

The larger mines have been opened to a depth of over 1,000 feet (300 m.) and are still productive, though the expense of mining and of treatment has in some cases led to a suspension of exploitation. The increasing proportion of zincblende is very disadvantageous in the amalgamation processes by which these ores are reduced.

Distinct methods of treatment are pursued for the two different classes of ore. The silver ores are pulverized in dry stamp-mills, subjected to desulphurizing-roasting, chloridized by mixture with salt, and amalgamated in revolving pans, after the Nevada system. For ores that are extremely refractory, owing to a large proportion of zinc-

blende, the Russell process of lixiviation, a modification of the hyposulphite process, has recently been introduced. The amalgamation mills, in which this process is carried on, are the most complicated and expensive of their kind. The finest here is that of the Bluebird mine, about 3 miles (5 km.) west of Butte, which cost over $300,000 and has 70 stamps, two Stetefeldt shaft furnaces, each 60 feet (18 m.) high, for the desulphurizing and chloridizing of the pulverized ore, and a lixiviation plant. The copper ores are subjected to preliminary concentration in ore-dressing works, roasted, and smelted to a rich matte. This matte is sometimes shipped East, sometimes reduced to metallic copper here. One smelter, the Colorado, smelts both copper and silver ores, producing a matte which has absorbed all the silver. This silver-bearing matte is sent to the great smelting words at Argo near Denver, to be treated by the Augustine-Ziervogel process. The salt used for chloridizing is brought by railroad from Great Salt lake.

From **Butte** the road runs westward 7 miles along the valley of Silverbow Creek, passing the Bluebird mill about midway in this distance, and crossing low ridges of recent rhyolite just before reaching **Silverbow** station, which lies in a broad valley of Quaternary gravels. The route now follows the line of the Utah and Northern division of the Union Pacific Railroad southward, traversing a series of low mountain ridges mainly made up of Paleozoic rocks, which form the geological connection between the north and south trending northern extension of the Wasatch mountains, and the northwest trending Bitter Root mountains. These ranges not only form the continental divide between east and west flowing waters, but represent in a general way the western limits of the mediterranean ocean of Mesozoic times. No geological examination has yet been made of the region, so that it is not possible to give exact indications of the age or character of all rock exposures along the route. It may, however, be safely inferred that they are mostly of Paleozoic strata and recent eruptive rocks, with a covering of Pleistocene gravels in the larger valleys.

Before reaching **Melrose** the road crosses a divide into the valley of a tributary of Jefferson river.

From **Dillon** it ascends the valley of Beaver Head creek, one of the main tributaries of this river, for a distance of over 50 miles; it then crosses the continental divide, which is the boundary between Montana and Idaho, on to the waters of the Snake river.

Beaver canyon, which is a gorge in basaltic lavas, is the point from which a stage line about 100 miles long runs to the Lower Geyser basin in Yellowstone National Park.[46] The road now traverses the northeastern portion of the Snake Plains and crosses the Snake river at Eagle Rock, from which it follows southward the eastern edge of the Snake River desert.

At **Ross Fork** is the agency of the Fort Hall Indian reservation, a tract of land set aside by Government for portions of the Bannock and Shoshone tribes. These Indians, who number 3,000 to 4,000, are peaceful and largely devoted to agricultural pursuits, raising hay which they sell to cattle owners whose herds graze on the neighboring hills.

Pocatello, near the southern edge of the Indian reservation, is at the junction with the Oregon Short Line which runs westward through Idaho to Portland, Oregon. It is on the Portneuf river, where it debouches from a narrow valley between rounded hills of Paleozoic rocks, partly filled by very recent flows of basalt, which are readily visible from the train as it ascends to the more open valley of Marsh creek.

EXCURSION TO SHOSHONE FALLS.

THE SNAKE PLAINS.

By S. F. Emmons.

The valley of the Snake river presents a most interesting study to the vulcanologist. From its source in the mountains around the Yellowstone Park to its junction with Clarkes fork of the Columbia, a distance of about 800 miles (1,287 km.), the rocks which environ it are mostly recent eruptive rocks or actual lavas. The Columbia river, formed by the junction of these two great streams, flows westward across the lava plains of eastern Oregon for about 120 miles (193 km.), and then debouches on to the lowlands of the Pacific coast, through the stately portal of the Cascade mountains, where, on either side, walls of basalt rise to 3,000 feet (914 m.) almost vertically, and at a little distance north or south the great extinct volcanoes of the Cascade range raise their snow-capped summits to altitudes of 10,000 to 14,500 feet (3,000 to 4,420 m.) above sea level. This interesting region has not yet been systematically surveyed and the little that is known of its geology has been obtained by reconnoissances of individuals and small exploring parties.

The Snake plains, properly speaking, occupy an area, whose dimensions are not accurately known, extending from the sources of the river some 250 miles (400 km.) slightly south of west, in its broader portion nearly 100 miles (160 km.) wide. This area, for the most part practically a plain of basaltic lava, is incidented here and there by low hills, either some slight preexisting elevation of underlying older rocks, or inequalities in the lava itself, but contains no high mountains. A general depression, or area without high mountains, extends westward beyond the valley of the Snake, and on the same general line, to 121°

of west longitude, or 10° west of the Yellowstone Park. This area is occupied by recent deposits of Pliocene or Pleistocene age and large sheets of recent eruptive rocks. The present bed of the Snake river leaves this depression at the eastern boundary of Oregon and flows northward 200 miles (322 km.), cutting a deep gorge in the mountains which lie across its path. There is some reason for assuming that this sudden change of direction is of geologically recent date and that an earlier valley existed further westward. The solution of this question, as to earlier draining and as to the age of the recent deposits in this valley, is of ethnological[47] as well as geological interest.

It will be seen later that the interior basin now occupied by Great Salt lake was once filled by a much larger lake called Lake Bonneville. At one period in its history Lake Bonneville overflowed and its superfluous water drained out through the Snake River valley. Whether the lavas, which now form the surface of the Snake Plains, were poured out before or after the dessication of this lake has not yet been definitely ascertained.

ITINERARY.

By S. F. Emmons.*

Station.	Distance.		Elevation.	
	Miles.	Kilometres.	Feet.	Metres.
Pocatello	0	0	4,466	1,360
American Falls	25	41	4,341	1,323
Shoshone	103	166	3,973	1,211
(By stage) to Shoshone Falls	26	42		

Those who take this excursion leave the Utah Northern train at **Pocatello** and take the regular train on the Oregon Short Line to **Shoshone** station, from which they reach the falls by stage.

At **American falls** the Snake river is reached. The falls can be seen on the left or below the bridge. A short distance above the bridge, wide, alluvial bottoms border the Snake River, which support a luxuriant growth of grass and large cottonwood trees, where cattle, which pasture on the hills further east, are taken during the winter.

From **American falls** downward, the river runs in an ever-deepening gorge in the basalt, whose walls at the bridge are about 70 feet (21m.) high, and at Shoshone falls, about 150 miles (241 km.) lower down the river, are 400 feet (122 m.) and 620 feet (190 m.) above and below the falls, respectively. After crossing the river, the railroad keeps a westerly course, slowly diverging from the course of the stream

* From notes furnished by J. P. Iddings and J. S. Diller.

which flows somewhat to the south of west. The country now assumes the desert aspect characteristic of the lava plains, treeless and waterless, the rocks bare or covered in the hollows with the common desert shrub, the sage-brush (*Artemisia*). No rivers flow into the Snake river from the north, although many bold mountain streams have flowed out upon the borders of the lava plains from the mountains which form its northern boundary. These are known as Lost rivers; and, while much of their water has undoubtedly been dissipated by evaporation, no inconsiderable portion must have found its way downwards through the cracks and rifts in the lava to the rocky bed over which it was originally spread out. This water, gathered into subterranean streams of considerable volume, pours out along the walls of the Snake river canyon to the southwest, below Shoshone falls, where the corrasion of the stream has cut down below the base of the basalt into the underlying andesite or dacite.

From **Shoshone** station the stage route leads south over the same monotonous barren plain, which has a scarcely perceptible inclination toward the river. Long before the canyon in which it runs can be distinguished in the level monotony of the plain, the presence of the stream is indicated by the thundering roar of waters as they fall. Suddenly one comes upon the brink of the gorge. A steep descent of 400 feet (122 m.) leads down to the banks of the river above the Shoshone falls.[43] The travelers are ferried across the river to a comfortable little hotel near the brink of the falls, having a view down the canyon below, which is 620 feet (190 m.) deep. These falls are more broken and varied than Niagara; their height is greater, being 212 feet (65 m.) instead of 156 feet (48 m.), but the volume of water is less, though still very great, especially in the early summer, and the country around has the desolate grandeur of the desert instead of the brilliant verdure of the thickly-populated region in the vicinity of Niagara.

The canyon presents a striking contrast to that of the Yellowstone river both in coloring and form. The Yellowstone canyon is brilliant and light-colored, with innumerable vertical pinnacles and spires; the Snake River canyon is somber and black, with predominantly horizontal lines marking the successive sheets of basalt, which are, however, vertically columnar. The first is cut in a rhyolite plateau, the second in a basalt plain.

The basalt consists of three sheets, which form the upper 250 feet of the canyon. The lower 250 feet, just below the falls, is massive andesite of an abnormal type, approaching dacite in chemical composition. Its upper portion near the ferry is glassy and resembles certain modifications of the rhyolite of the Yellowstone National Park. Where the plateau of the Yellowstone Park descends into the plain of the valley of the Falls river, a tributary of the Snake, the same geological

structure exists. An acid lava (rhyolite) forms the bed of the stream and is overlain by a sheet of basalt.

A short distance above Shoshone falls are the Upper or Twin falls, about 180 feet high, which drop from a cliff formed by the two lower sheets of basalt. Red tuff and volcanic agglomerates are found in places between the successive sheets of lava.

A hundred miles or more further down the stream the basalts have been observed to rest directly on sedimentary beds of recent age, probably deposited in some inclosed fresh-water lake. Other cascades and falls are known to exist along the course of the Snake River, but its canyon has never, so far as known, been followed continuously, and their number and its extent is unknown. The stream is unusually rapid for its size, in spite of these many leaps in its course, and is cutting down its bed very fast, though yet far from reaching a baselevel of erosion. From longitude 112° W. to longitude 117° W. its total descent has been about 2,500 feet (762 m.).

GREAT SALT LAKE AND LAKE BONNEVILLE.[49, 50]

By G. K. Gilbert.

A large district of interior drainage, lying to the west of the Wasatch mountains and the Plateau region, is known as the Great basin. It includes nearly the whole of the state of Nevada, the western half of Utah, and smaller portions of Idaho, Oregon, and California. It is naturally subdivided into a number of smaller basins, from each of which the entire product of precipitation is evaporated, so that there is no discharge to the ocean. In most of the basins there are no permanent lakes, but temporary lakes are produced by the waters of each great storm. In a few basins there are permanent lakes with saline waters. The largest of these is Great Salt lake, which receives the waters of the Bear, Weber, and Jordan rivers, and has an area of about 1,800 square miles (4,500 sq. km). The extent and depth of the lake are determined by the balance between inflow and evaporation. In years of great rainfall the surface of the lake rises, and in dry years the waters recede. During the past thirty-five years the water height has several times oscillated through a range of 11 feet (3·3 m.), and it is now (1891) near its lowest observed stage. The salinity undergoes corresponding changes, being greatest when the lake is low. The solid contents now amount to about 20 per cent, of which four-fifths is sodium chloride. Sodium sulphate is naturally precipitated by the cold of each winter, and afterwards redissolved. The lake is very shallow, having a mean depth of 13 feet (4 m.) and a maximum depth of less than 40 feet (12 m.). It is inhabited by a brine shrimp and the larva of a fly.

In Pleistocene time the lakes of the Great basin were larger, and many perennial lakes were formed in valleys whose floors are now saline and desert. Great Salt lake was expanded so as to coalesce with the lakes of contiguous basins, producing a body of water 19,750 square miles (51,000 sq. km.) in extent, which has been named Lake Bonneville. This lake was twice formed and twice dried away, each time depositing over the plain a sheet of calcareous clay with fresh-water fossils. The two sheets of clay are separated by an unconformity, the first having been eroded before the second was laid down. In some places, moreover, a wedge of alluvial gravel intervenes between the two clays, showing that the lacustrine epochs were separated by an arid interval, during which alluvial deposition took place, as at the present time.

The highest water stage was attained during the second lacustrine epoch, and is recorded in a conspicuous series of sea cliffs, terraces, and beaches known as the Bonneville shore line. This shore line has a general altitude of 1,000 feet (300 m.) above Great Salt lake, or 5,200 feet (1,580 m.) above the ocean, but its height varies from place to place, ranging in the vicinity of Great Salt lake from 960 feet (290 m.) to 1,050 feet (320 m.) above the modern water surface. As all parts of the shore line were produced at the same time, their present differences in altitude indicate a warping of the earth's crust since the period of their formation.

At this stage the lake overflowed the northern rim of its basin, and the channel of outflow was eroded to a depth of nearly 400 feet (120 m.), when the cutting was arrested by a ledge of limestone and the water was held for a long period at one level, giving the waves time to sculpture a second series of terraces, etc., constituting the Provo shore line. At many heights between the Bonneville shore line and the Great Salt Lake shore line, the waves of the oscillating water have left their traces, so that the number of fossil shore lines is very great; but the Provo shore line is distinguished from all of these by the magnitude of its features. Its terraces are broader, its cliffs are higher, its spits are greater, and with it are associated great delta terraces built by tributary creeks and rivers during the Provo epoch.

During the long period for which the lake maintained an outlet its water must have been completely freshened, so that the salt contained in the modern lake has all been accumulated in recent times. A comparison of the high salinity of the modern lake with the approximate purity of its tributaries enables one to realize the antiquity of the Provo epoch, and yet in this arid climate the vestiges of wave action have been preserved almost unscathed.

FAULT SCARPS.[49]

By G. K. Gilbert.

The mountains of the Great basin are, in large part, carved from orogenic blocks uplifted along fault planes. The displacements, which were probably initiated in Mesozoic time, were continued during various Cenozoic epochs, and are now in progress. The steeper faces of most of the mountain ranges are rugged escarpments primarily due to faulting, and at their bases are frequently to be found smaller escarpments of so recent date that the traces of subsequent erosion are scarcely perceptible. In 1872 the production of such a fault scarp along the base of the Sierra Nevada was accompanied by an earthquake. In connection with the earthquake in Sonora, Mexico, in 1885, other scarps were produced. In the Salt Lake basin there is no historical record of their formation, but many of them intersect the beaches and deltas of the Bonneville shores, and some are so fresh that vegetation does not yet clothe them, and it is hard to believe their antiquity is measured by centuries rather than decades. They have been found along the bases of a dozen ranges of the Salt Lake basin, but they are most persistent and have greatest magnitude at the western base of the main ridge of the Wasatch chain, where they have been traced almost continuously for a hundred miles.

As a great orogenic block, separated from another by a fault plane, rises, the débris resulting from its sculpture is thrown upon the block beyond the fault, and rests as an alluvial bank against the cliff produced by the faulting. When subsequent movements occur on the same fault plane they are superficially manifested either in the alluvium, or at its plane of junction with the rock. The forms of the alluvium, being determined by the laws of fluvial deposition, are regular, and the cliffs produced by the faulting are thus rendered conspicuous and unmistakable. Sometimes a single scarp is seen to cross an alluvial slope, rising and falling as the slope rises and falls; sometimes two or more scarps are seen to run parallel to each other, and in such case the intervening surfaces of alluvium have new attitudes, their tendency being to incline toward the mountain face; sometimes a wedge of alluvium has fallen into the fissure due to faulting, so as to produce a trench on the alluvial surface.

All these special phenomena are illustrated in the localities to be visited by the Excursion party, and the fault scarps of the Wasatch can also be observed, at a distance, from the windows of the train.

OUTLET OF LAKE BONNEVILLE AT RED ROCK PASS.

POCATELLO, IDAHO, TO SALT LAKE CITY, UTAH.

ITINERARY.

By G. K. Gilbert.

Station.	Distance. Miles.	Distance. Kilometers.	Elevation. Feet.	Elevation. Meters.	Station.	Distance. Miles.	Distance. Kilometers.	Elevation. Feet.	Elevation. Meters.
Pocatello	0	0	4,466	1,360	Dewey	97	156	4,318	1,316
Portneuf	6	10	4,495	1,370	Brigham	113	182	4,313	1,315
McCammon	23	37	4,753	1,449	Utah Hot Springs	125	202	4,275	1,303
Thatcher	34	55	4,818	1,468	Ogden *	134	216	4,301	1,311
Oxford	53	85	4,774	1,455	Kaysville	151	243	4,298	1,310
Battle Creek	64	102	4,490	1,368	Lake Shore	158	254	....	....
Cache Junction	85	137	....	....	Salt Lake City †	170	274	4,228	1,289
Collinston	92	148	4,689	1,429					

* Population, 14,899. † Population, 44,843.

From **Pocatello** the railroad line runs a few miles eastward up the narrow defile of the lower Portneuf valley, then bends southward, following for 35 miles (56 km.) the broad Pleistocene valley of Marsh creek. In the middle of these valleys, and sometimes filling their bottoms so as to block up the mouths of the tributary ravines, are recent flows of basaltic lava.

Marsh valley lies between parallel mountain ranges trending with the meridian and consisting, so far as known, of Paleozoic rocks. They may be considered as northern members of the Wasatch chain. They belong to an ancient topography whose drainage system has been considerably modified in geologically recent time. The Portneuf river breaks into the valley from the east at a point about midway, follows it to its northern end, and escapes by the defile just mentioned. Late in Tertiary or early in Pleistocene time a flow of basaltic lava followed the course of the river into the valley. Subsequent erosion, chiefly by the outlet of Lake Bonneville, lowered the drainage system of the valley so that the basaltic coulée stands at the top of a steep-sided mesa. The Bonneville channel follows the western margin of this mesa, and the Portneuf river follows the eastern, breaking across it at the northern end of the valley. The train follows the river for several miles, then

rises to the eastern alluvial slope of the valley, and finally descends to the Bonneville channel at a point beyond the lava tables.

Where the Portneuf skirts the lava bed its channel is obstructed by a series of low dams of travertine, which seems to be rapidly deposited by the water of the river.

At its southern end Marsh valley joins the northern end of Cache valley, being separated by a low divide known as Red Rock pass. Through this pass Lake Bonneville discharged its surplus water, and it is here that the train passes from the basin of the Columbia river to the basin of Great Salt lake. A halt will be made for the purpose of examining the channel of outflow (Plate v).

At this point a low ridge of Carboniferous limestone lies athwart the valley trough, its crest projecting above the alluvium in two buttes, whose iron-stained cliffs give name to the pass. Near them are Pliocene lakebeds, upturned at a high angle, but these are seen only where the alluvium has been washed away. The alluvium derived from the mountain ranges rests in great conical heaps against them, the cones joining along the middle of the valley. At the pass is an exceptionally large alluvial cone, built by Marsh creek, which issues from a canyon at the east (left). Before Lake Bonneville existed this formed the summit of the pass, and when the lake broke over its edge the alluvium was washed away with speed, letting the imprisoned waters escape to Marsh valley in a debacle of tremendous power. Marsh creek then cut a channel through the cone it had previously built, and in this channel it still flows. It has built a small cone in the abandoned river channel, which it is feebly laboring to fill. A little farther south other creeks have built alluvial cones in the Bonneville channel, partitioning it into little basins occupied by swamps and ponds. In time of flood Marsh creek turns northward and follows the old channel to the Portneuf, but it ordinarily sinks in its own alluvium near the pass.

The Mormon town of **Oxford** lies just beyond Red Rock pass in the northern end of Cache valley. Cache valley also lies between mountain ranges of the Wasatch system, trending north and south. It is traversed by the Bear river, the largest tributary of Great Salt lake, which enters the valley through a canyon at the northeast and, after traversing half its length, escapes to the west through a narrow gorge in Paleozoic limestone known as "The Gates." It is joined by many smaller streams issuing from the eastern range. The mountains on either side are constituted chiefly of Paleozoic strata, but fresh-water beds referred to the Pliocene (Humboldt beds) rest against their flanks at several points and have shared in the later displacements. Bonneville shore lines encircle the valley, and marl deposits of the same date occupy its lower levels. Associated with these are great delta deposits accumulated chiefly at the date of the Provo shore line.

THE GATES OF BEAR RIVER.

The largest ancient delta is that of the Bear river, but those formed by some of the smaller streams are more symmetrical. That built by Logan river has the form of a semicircular terrace projecting into the valley, its upper surface constituting an obtuse cone whose apex is at the mouth of the mountain gorge whence issues the river. By subsequent action the river has divided the terrace into two parts, and there are other delta terraces at lower levels. Upon these terraces stands the city of Logan on the east side of the valley Near the base of the mountain the Logan delta is traversed by a fault scarp, 6 feet (2 m.) high. Cache valley lies chiefly in Utah and contains a large number of thriving settlements founded by the Mormons. Their chief industry is agriculture, and this is carried on by the aid of artificial irrigation, the waters of the streams being diverted from their channels and carried by ditches to the farming land. The principal town, Logan, has a population of 4,565.

Northward from Red Rock pass the railroad traverses for several miles a plain little below the level of the pass and then descends to the immediate valley of Bear river, which is followed to the "Gates" and beyond (Plate VI). The passage opened by the river through the western mountain ridge exhibits a nucleus of Paleozoic limestone, against which on each side rest Humboldt beds. These last are upturned to 45° at the east and to 15° at the west, and are in turn overlain by marls, sands and tufas of Bonneville date. The erosion of the river gorge was pre-Bonneville, and its sides are sheeted by calcareous tufa to a depth of several feet. In sections opened by the railway the tufa is seen to have been deposited in two or more sheets separated by bodies of talus believed to represent one or more inter-lacustrine epochs. Here a great engineering work is in progress. By a dam near the head of the gorge the water of the river is diverted into two canals, which have been carried, partly through tunnels, along the walls of the gorge and then led out along the upper benches of the plain to the west. By their aid a large tract of desert land will be reclaimed to agriculture.

After passing through "The Gates" the road runs southward, between the steeper mountain slope on the left and the valley of Bear river on the right. A fine view is obtained, across the valley, of the Promontory range, which forms its western boundary, 40 miles (65 km.) away. This range is so called because it extends into Great Salt lake, dividing its northern portion into two great bays.

The road passes the Mormon towns of Willard, Box Elder, and **Brigham,** resting on the gentler slopes of the valley and surrounded by fields irrigated by waters from the mountain streams issuing from ravines behind them. Beyond **Brigham** the road passes round a projecting point of the Wasatch mountains, opposite the north end of Great Salt lake, to **Utah** (Bonneville) **Hot springs,** which issue from

the great Wasatch fault. They have a maximum temperature of 130° (58° C.) and leave a ferruginous deposit.

At **Ogden**, an important Mormon town of 15,000 inhabitants, the road crosses the Union Pacific railroad, the pioneer transcontinental line, which reached here in 1869, crossing the Wasatch range through the deep gorge of Weber river. In Bonneville time this river built an immense delta of sand and gravel on the margin of the plain.

From **Ogden** the road makes a detour to the westward around this delta and follows the lower level of the valley, near the lake, past the Mormon towns of **Kaysville**, Farmington, and Centerville. Fault scarps are continuously visible along the base of the mountains, being especially conspicuous near Farmington.

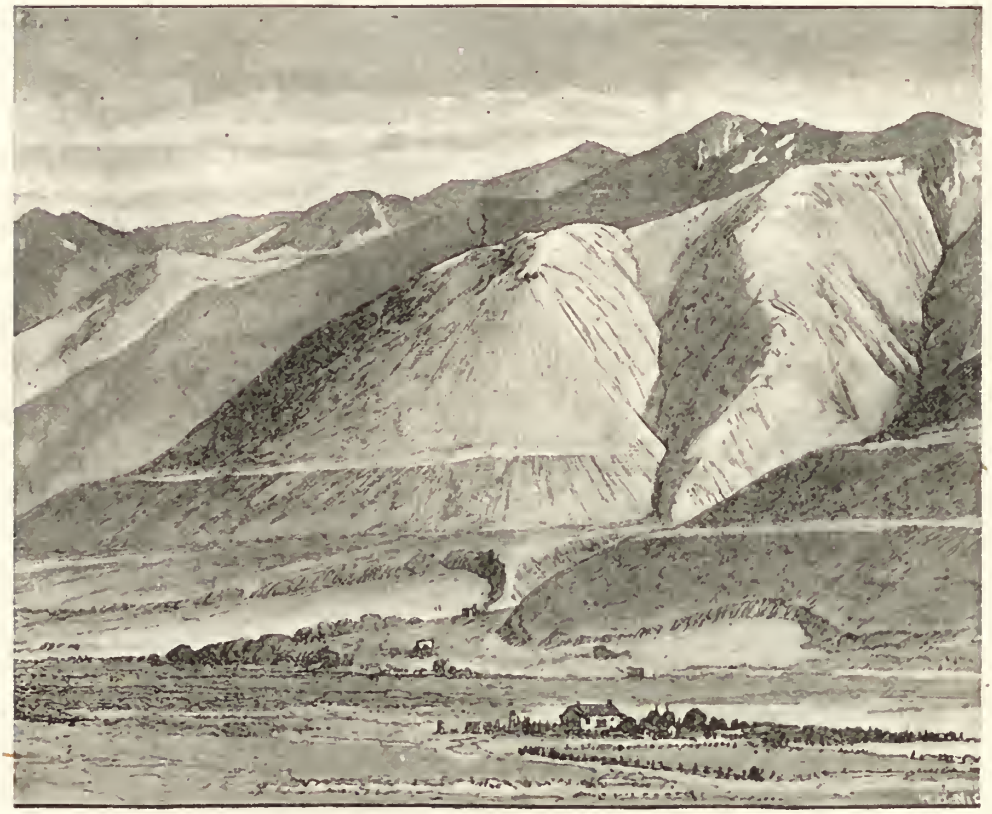


FIG. 17.—Shore lines and fault scarps near Farmington.

The road now passes around another low promontory of the Wasatch, opposite the southern end of the lake, to **Salt Lake city**, which lies to the south of the promontory. Near **Salt Lake city** are both warm and hot springs, also issuing from the great fault, with a maximum temperature of 123° F. (53° C.).

THE WASATCH MOUNTAINS.

By S. F. Emmons.

The Wasatch Range, whose imposing western front the party will pass in review, is one of the most important single chains in the whole Cordilleran system. Within its mass may be found representatives of all the great geological formations recognized in the western United States, and as a rule developed in greater thickness than the same horizons show elsewhere in the system. Its topographical relations are also somewhat interesting. All the waters drained from its slopes, whether on the east or on the west, flow finally into Great Salt Lake, which lies at its western base, and these waters are practically the only feeders of the lake. Thus the lake constitutes a great hydrometer, which measures the relation between the amount of water precipitated upon the mountain range and that taken up by the dry desert winds which sweep over its glassy surface. The general level of the lake surface is about 4,200 feet, but the actual rocky bottom of the great valley in which it lies must be far deeper, for borings through the lake deposits, which fill up the inequalities of its surface, have gone down 1,500 feet in places without reaching the underlying rocks. The western or higher crest of the range rises abruptly from 5,000 to nearly 8,000 feet (2439 m.) above the present surface of the valley plains.

Its present form, geologically considered, may be said to represent only the eastern portion of the original range, the western half having been sheared off and sunk below the valley level by a great fault, which followed closely the line of its present western base.

The internal geological structure of the Wasatch range is most complicated, and the various dynamical movements by which it was produced, if thoroughly and accurately worked out, would present an epitome of the geological history of the greater part of the Cordilleran system. The range was first systematically studied in 1869 by the geologists of the exploration of the Fortieth parallel, and the preliminary determination of horizons thus made served as a basis for later determinations throughout the whole breadth of the Cordilleran system. The following table shows the general geological column of the Cordilleran system as a whole, as represented here.

Group.	System.	Series.	Where found.
Cenozoic	Pleistocene	Bonneville Lake beds	Great basin.
	Pliocene	Wyoming conglomerate	Uinta mountains.
		Humboldt	Cache valley.
	Miocene	Truckee	In Nevada.
		White River	East of Rocky mountains.
	Eocene	Bridger	Wasatch and eastward.
		Green River	Wasatch and eastward.
		Wasatch (Vermillion Creek)	Wasatch and eastward.
Mesozoic	Cretaceous	Laramie	Wasatch and eastward.
		Montana (Fox Hills)	Wasatch and eastward.
		Colorado	Wasatch and eastward.
		Dakota	Wasatch and eastward.
	Jurassic		Wasatch and eastward.
	Triassic	Red beds	Wasatch and eastward.
Paleozoic	Carboniferous	Permo-Carboniferous	Wasatch and eastward.
		Upper Carboniferous	Wasatch east and west.
		Weber (grits and quartzites)	Wasatch east and west.
		Lower Carboniferous	Wasatch east and west.
		Sub-Carboniferous	Wasatch east and west.
	Devonian	Nevada (limestone)	Wasatch and westward.
		Ogden (quartzite)	Wasatch and westward.
	Silurian	Ute-Pogonip (limestone)	Wasatch east and west.
	Cambrian	Middle Cambrian	Wasatch and westward.
		Lower Cambrian	Wasatch and westward.
Pre-Paleozoic	Huronian (Algonkian)		Wasatch east and west.
	Archean		Wasatch east and west.

While in the more recent phase of its geological history the range is a great faulted block, the internal structure of that block proves the existence of a succession of more ancient mountain ranges of complicated structure produced by a succession of orographic movements at different periods in the earth's history, of which only the most brief and scanty outline can here be given.

The following great transgressions or unconformities have been observed, which mark critical epochs in its geological history:

First. At the close of the Archean.

Second. During Algonkian or Pre-Cambrian times.

Third. At the close of the Paleozoic.

Fourth. Toward the end of the Jurassic.

Fifth. At the close of the Mesozoic.

Sixth. The final uplift in Tertiary times, which is continuing to the present day.

Of these movements the First, Third, and Fifth were the most widespread, and have left the most definite evidence of their existence, not only here, but in other parts of the Cordilleran system.

The post-Archean transgression is here, as elsewhere, most distinct and easily recognizable, and the positions which the succeeding sedimentary beds bear to the massives of ancient crystalline rocks, show that they must have been deposited on the flanks of lofty and precipitous mountain masses. Of the rocks which were first deposited against these shores the outcrops are very limited and have been but slightly studied. The great thickness of Paleozoic beds, which form the principal mass or main crest of the range, rest upon the projecting massives of Archean rocks; not in regular folds with parallel axes, as in the Appalachian system, but wrapping around them, with curving strike and ever-changing dip, in anticlines and synclines with axes of varying trends, which, on the eastern flanks of the range, are still partly buried beneath the beds of the Tertiary transgression.

The movement at the close of the Paleozoic is proved by no discernible angular discrepancy in the position of beds deposited before and after it, but by the change in the character of sedimentation and by the striking fact that the crest of the range marks the western limit of deposition of Mesozoic beds in this latitude. From the meridian of this range (112° W. long.) to long 117° 30′ W. (from Greenwich), no trace of Mesozoic beds has been found, and those that exist west of the latter are of entirely different character, both lithological and paleontological, from those found east of the Wasatch range.

The transgression about the close of the Jurassic is shown by a discrepancy of strike rather than of dip, and even this, in the Wasatch mountains, is not very marked but is well developed further east, especially in the Rocky mountains of Colorado.[59] A considerable thickness of Lower Cretaceous beds is found to the north, in British Columbia (Kootanie beds), and in Texas, east of the mountains and south of the Great Plains (Comanche beds), which are wanting in the Wasatch and in Colorado.

The transgression at the close of the Laramie (coal-bearing) Cretaceous is the most distinctly marked and most readily observed, next to that at the close of the Archean. It is generally (though not always) shown by a marked unconformity of angle between the Laramie and succeeding deposits. The earlier deposits with unimportant exceptions are marine, the Laramie brackish water, and all succeeding deposits in the interior of the Cordilleran system of fresh-water origin.

In the Wasatch region the succeeding Eocene Tertiary conglomerates overlap the eroded edges of all the earlier series, and even rest upon denuded Archean high up on the western slopes of the range. They generally constitute the greater portion of the high table-lands or mesas which form the eastern and southern continuation of the Wasatch uplift.

The Tertiary transgression, or transgressions (for there have been

several), are less readily defined and are apparently rather local in their nature. In places, especially on the immediate flanks of the mountain massives, the elsewhere horizontal Tertiary beds are found to be upturned at considerable angles. In the great Tertiary basin of Green river, east of the Wasatch and north of the Uinta mountains, there is evidence of dynamic movement, and of a limited amount of erosion, at the close of each of the three Eocene epochs there represented.

The principal plication of the Wasatch range must have taken place at the close of the Cretaceous, and at this time also was formed the great east and west anticline of the Uinta Mountains, which stretches 150 miles eastward from the eastern flank of the Wasatch, opposite the great granite mass of Little Cottonwood canyon. That the movement of uplift of this range has been, in a measure, continued in Tertiary times, is proved by the fact that the Tertiary beds resting upon its flanks are also bent upwards; but the angle at which they are upturned, even in the lowest and most disturbed of these Eocene series, is much lower than that of the Cretaceous beds, while those of the two upper series often pass in a nearly horizontal position completely over the eroded edges of the upturned Cretaceous strata.

Erosion, since the deposition of the Eocene Tertiary beds, has carved out many interior valleys to the east of, and generally parallel with, the main crest of the Wasatch range, and this erosion has exposed portions of the underlying upturned beds. Over the greater part of the plateau region immediately west of the crest, however, the Tertiary covering still remains and masks their structure.

The broad general features of structure of the older part of the range, as far as it has been made out, are as follows:

At the north is a great syncline trending to the west of north, in whose eroded axis lies the great depression of Cache valley. The western flank of this syncline forms the front of the range from "The Gates" south to Brigham city. From here south to beyond Farmington stretches the Farmington Archean body, one covered by an arch of sedimentary beds. The western portion has been cut off by the great Wasatch fault, and the remainder in great measure denuded of its covering of sedimentary beds. Southeast of Salt Lake city is the great granite body of Little Cottonwood canyon, assumed to be of post-Archean age, though the crystalline rocks through which it was intruded are now considered Algonkian. The position of the overlying sedimentary beds, and the fact that their lowest members contain fragments of granite in the immediate vicinity of that body, prove that it is certainly pre-Cambrian. Included between the Farmington and the Cottonwood masses is a syncline of beds ranging from Cambrian to Cretaceous, whose axis runs nearly east and west. These upturned beds wrap round either of the older masses on the east; that is, the strikes of beds form-

ing either member of the synclinal fold diverge fan-like to the eastward and curve respectively to the north and south around either body. The western extension of the syncline, were it not for the fault, would pass above Salt Lake city. It probably lies at some depth beneath it.

South of Lone Peak the granite sinks beneath the surface, and the range opposite the valley of Utah Lake is formed of a flat arch of Paleozoic beds, half of which has been cut off by the fault and depressed beneath the valley level.

The accompanying map (Fig. 18) is a reduced copy of the geological map of the range in the atlas of the Fortieth-parallel reports, of which Dana [52] says: "It is the grandest exhibition of facts pertaining to an individual case of mountain building in geological literature." *

GEOLOGICAL PANORAMA OF THE WASATCH RANGE

AS SEEN FROM THE RAILROAD.

By S. F. EMMONS.

From the northern point of the range to **Brigham** its east front shows a series of northwesterly dipping beds, ranging from Lower Carboniferous limestones, through Devonian and Silurian, to Cambrian at **Brigham**.

From a distance one can distinguish the different series of beds by their colors, the limestones being very dark, the quartzites light in color. Thus in this part of the range the white Cambrian quartzites at the base of the sedimentary series are sharply contrasted with the dark band of Silurian limestone, and this again from the overlying light Ogden quartzite at the base of the Devonian.

The depression in the range south of **Brigham** marks a line of strike-fault, running southeast with downthrow to the southwest, by which the Cambrian and Silurian beds are repeated on the mountain-mass projecting westward from the main line of the range, round which the railroad bends in going to **Hot Springs**.

At **Hot Springs** the waters issue from outcrops of Cambrian quartzite, forming part of a mass of quartzite and limestone, broken down by the great Wasatch fault from the beds which now cap the high peak to the east. On this peak the white line of Cambrian beds, with a thin cap of

* The small scale of this map necessitates the omission of many topographical and some geological details. It serves, however, to illustrate the general outlines of structure as above described, and shows the western end of the broad anticlinal arch of the Uinta mountains.

On the western base of the range B. C. indicates the mouth of Big Cottonwood canyon; L. C., that of Little Cottonwood canyon. Figures denote elevation in feet above sea level.

FIG. 18—Outline geological map of the Wasatch mountains.

darker limestone above, can be readily distinguished at the very crest, while the lower part of its steep western face is formed of darker structureless Archean rocks.

At a re-entering angle of the mountain front, just south of the Hot Springs, known as Ogden's Hole, is a transverse fault at right angles to the trend of the range, whose movement has been a downthrow on the south, by which movement the Cambrian and Silurian are brought down to the foot of the steep western face of the mountains, while Lower Carboniferous limestones form the crest of the ridge.

Directly east of Ogden city is Ogden canyon, a narrow gorge cutting entirely across the range, and connecting with a small interior valley, once a bay of Lake Bonneville, which affords an admirable exposure of the whole series of rocks from the Archean up to and through the Lower Carboniferous.

Just south of Ogden canyon a smaller ravine marks the line of another transverse fault, with upthrow to the south, by whose movement the Archean rocks on the south are brought nearly to the crest of the range, with a thin covering of Cambrian quartzite which disappears to the south.

A few miles south of Ogden is the still deeper gorge cut by Weber river, which drains a large portion of the eastern slopes of the Wasatch. The Rio Grande Western railroad passes round a delta of the Bonneville Lake beds that in great measure hides this fine gorge. The gorge affords an admirable section from Archean up to Cretaceous and unconformable Tertiary beds, which can be seen along the line of the Union Pacific railway as it crosses the mountains.

From Weber canyon southward for nearly 20 miles (32 km.) the crest and west front of the range is of Archean rocks; while coarse Tertiary conglomerates rest high up on the eastern flanks and conceal all the lower beds. At the southern end of this Archean mass the older sedimentary beds appear again, through denudation of the conglomerates, striking nearly east and west, and dipping southeast and south away from the Archean. These upturned beds, broken through by eruptive rocks and partly covered by Tertiary beds, jut out to the westward of the main front of the range, forming a projecting promontory between the Mormon town of Centerville (east of Lake Shore station) and Salt Lake city.

This promontory is formed of steeply upturned Paleozoic beds, partly covered by a coarse conglomerate of supposed Tertiary age and an eruptive body of trachyte or andesite. The Warm Springs at the point of the promontory issue from the much broken Paleozoic limestones. The canyon of City creek, directly north of Salt Lake city, cuts through the conglomerate and eruptive body, and near its head,

beyond the conglomerate, primordial trilobites have been found in the shales at the base of the limestones.

To the north of Camp Douglas, the United States military post three miles (4.8 km.) east of the city, are upper Carboniferous and Permian beds, mostly limestones, carrying characteristic fossils. Red Butte canyon, northeast of Camp Douglas, marks the dividing line between the shaly limestones of the Permian and the pink red sandstones of the Trias. The latter furnish much of the building stone for Salt Lake city. Above these, dipping 40° to the southeast, are the drab limestones and argillaceous shales of the Jurassic. These beds strike about N. 40° E., and thus cross the ravines whose direction is more nearly east and west. Emigration canyon, directly back of Camp Douglas, lies nearly in the axis of the synclinal fold included between the two great Archean masses to the north and south (3 and 4 on the map).

Going south from Emigration canyon, along the foothills, one crosses the ends of a series of beds dipping north and northwest, ranging in geological horizon from the Jurassic down to the base of the Cambrian, a thickness in round numbers of 35,000 feet (10,750 m.).

Between Emigration and Parleys canyon a secondary anticline brings up the Permian beds from under the Trias. At Parleys canyon, up which runs the narrow-gauge railway to Park city, the Permian beds are again exposed with the regular northerly dip. They carry abundant Permian forms, *Aviculopecten*, *Eumicrotis*, *Myalina*, etc.

Mill Creek canyon, the next to the south, is in the Weber quartzites of the Middle Carboniferous. South of this is a re-entering angle of the foothills in which the outcrops are more covered by débris and the succession less easy to trace. The high projecting spur beyond is formed of the great mass of Cambrian [53] quartzites and slates striking northwest and dipping 45° to the northeast.

An excellent section across these beds and up into the Carboniferous is obtained by following up the next canyon gorge, called Big Cottonwood, as the beds curve in strike more to the southward at the upper part of the canyon, wrapping around the granite body of Little Cottonwood canyon.

The section (Fig. 19), on a nearly east and west line through Twin Peak, a little south of Big Cottonwood canyon, shows the position these beds occupy relatively to the granite. The lowest Cambrian beds, near the contact with the granite, contain fragments of the latter, showing its eruption to have been at least Pre-Cambrian, and that all these beds were deposited around it, and have been subsequently uplifted into their present position,

The next canyon south, known as Little Cottonwood, is a deep glacier-carved gorge cut almost its entire length in granite, but showing easterly dipping Paleozoic beds at its very head. The steep face of Twin

Peak (11,560 feet or 3,523 m. elevation) forms its northern wall, which is mostly granite, but with Cambrian quartzites forming the summit ridge as shown in the section. The foothills between the mouths of Little and Big Cottonwood canyons are formed of a series of crystalline schists dipping westward away from the granite body, which are represented by the blank space at left of section. At the contact the granite sends veins into these schists, and also includes fragments of them within its mass, which proves its later age. This series of beds was considered by the geologists of the Fortieth parallel survey to probably represent the Huronian division of the Archean; further study may lead to their inclusion in the Algonkian.

South of this canyon the second highest point of this portion of the range, Lone peak [51] (11,205 feet (3415 m.) elevation) is about the center of the great granite mass whose exposed area measures 8 by 12 miles (13 by 19 km.). An encircling series of lower Paleozoic beds wraps around its northern, eastern, and southern sides, and a thin shell of crystalline schists rests upon its western flanks forming the extreme foothills toward the Jordan Valley.

On the ridge forming the southern wall of the entrance to Little Cottonwood canyon

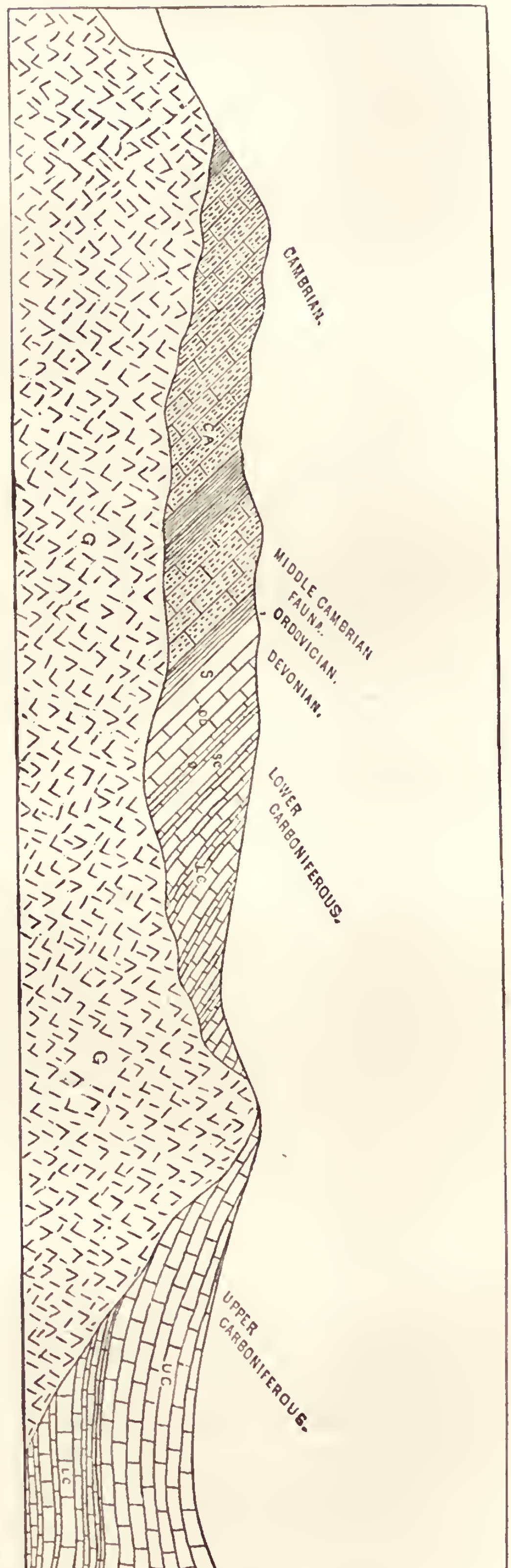


Fig. 19.—Section between Big and Little Cottonwood canyons.

is a fragment of quartzites and limestones to the west of the outcrop of crystalline schists, which represents a portion of the overlying Paleozoic beds brought down by the great Wasatch fault. These lie somewhat to the eastward of the line of faulting in the Pleistocene deposits of the valley.

At the head of the two Cottonwood canyons is Claytons peak, a boss of granite projecting through the Paleozoic beds, and to the east of this, on the east slopes of the Wasatch range, are extensive areas of eruptive rocks. It is in this portion of the range alone that important mines have thus far been developed. The most prominent have been the Emma mine, in Paleozoic limestones at the head of Little Cottonwood canyon, and the Ontario mine, a strong fissure vein worked to a depth of over 1,000 feet (305 m.) in Middle Carboniferous quartzites, with associated porphyries, which has produced over twenty millions of silver and is still paying dividends.

From the southwestern extremity of the Lone peak granite mass a low ridge of eruptive rocks, resting on altered sedimentaries of unknown age, stretches across the valley from the Wasatch to the Oquirrh range. This separates the valley of Salt Lake from that of the fresh water Utah Lake. This lake is fed by four principal streams, which drain interior valleys to the east of the main crest of the Wasatch, and cut deep transverse gorges across it, which afford admirable sections of the range. These are American Fork, Provo river, Hobble's creek, and Spanish Fork. The former shows a broad anticlinal arch, and the great mass of Timpanogos peak south of it, nearly 12,000 feet (3,667 m.) in height, is formed of horizontal Paleozoic beds forming the crest of this arch. The axis of this fold runs somewhat east of south and to the west of the crest of this peak, following the line of a projecting shoulder; it is somewhat broken, and in Provo canyon, next south, is only visible as a fault line with the beds somewhat curved upward near to it.

South of Provo canyon a second line of folding and faulting, en échelon and set off a little to the west of this, is developed back of the town of Provo at the base of Provo peak. The section seen in Rock canyon, back of this town, shows lower Paleozoic beds sharply upturned in an S-fold, which sometimes pass the vertical in dip, but a short distance eastward shallow almost to the horizontal position. Quartzites and schists occur at the base of the series. While the lines of strike continue in a direction east of south the range itself assumes topographically a direction more and more to the west of south.

In Hobble's canyon, and in Spanish Fork canyon through which the Rio Grande Western Railroad passes, only upper members of the Paleozoic series are seen, dipping somewhat south of east at 25°. To the south of this the range consists of mountain masses set off successively more to the westward, which culminate in Mount Nebo, 12,000 feet

(3,657 m.), 20 miles (32 km.) to the south and about 12 miles (19 km.) to the west of the Timpanogos line of elevation. This peak is formed by a sharp anticline of Paleozoic beds, the axis of which is near the summit. The eastern member of the anticline stands almost perpendicularly and soon disappears under unconformable Mesozoic and Tertiary beds, while the western member dipping 40° to 45° west forms a long and more gentle slope. This is the geological termination of the Wasatch range, as a complex mass of folded and faulted Paleozoic strata. Its topographical continuation to the south is found in a series of high tablelands or mesas, formed of Mesozoic and Tertiary beds, known as the High Plateaux. [54]

GREAT SALT LAKE VALLEY.

By G. K. GILBERT.

Salt Lake city.—A body of Mormons, or members of the Church of Jesus Christ of Latter-Day Saints, founded this city in the midst of a wilderness in 1848, more than twenty years before the construction of the first railway. From that time it has received a continuous growth by Mormon immigration, and from it have been colonized nearly the whole of Utah and portions of adjacent Territories. Agriculture and grazing are the chief industries, and the development of mines has been discouraged by the church. But mines were, nevertheless, developed, and the mining industry drew into the Territory a considerable body of Gentiles, by which title non-Mormons are known. Municipal control in Salt Lake city has recently passed for the first time from the hands of the Mormons into the hands of the Gentiles.

The head of the Mormon church is called president, and the office is now filled by Wilford Woodruff. The members of a high council of twelve are called apostles, and other officers are known as elders, hundreds, and bishops. The bishops have important secular functions, one being placed in charge of each settlement and of each ward of the city. The church is sustained by tithes, a tax of 10 per cent on the incomes of its members. Payment is made chiefly in produce, which is gathered in tithing houses and placed on sale at fixed rates. The principal meeting house of Salt Lake city is called the Tabernacle, and its auditorium has a seating capacity of about 8,000. It is architecturally unique, having the form of half an egg shell. A more imposing structure, known as the Temple, is used for secret ordinances of the church, and visitors are not permitted to examine the interior. Other objects of interest connected with the church are: the Lion house, where a large part of the late Brigham Young's polygamous family resided; the Emma palace, built by him as a residence for his favorite wife, but

never used for that purpose; and Zion's Cooperative Mercantile Institution, the headquarters of a commercial system organized and conducted by the church.

Polygamy, which was formerly enjoined by the church upon its members as a duty, has, after long and bitter conflict with the United States Government, been abandoned.

The system of irrigation can be conveniently examined in the suburbs of the city.

Fault scarps near the Thermal springs.—Along the base of a great range like the Wasatch a vast amount of alluvium is deposited. On the steep slopes of the mountain gorges erosion is rapid, and the resulting detritus is rolled forward by the torrents and deposited on the plain outside the line of mountain front. Between the canyon mouths the waste from the mountain face produces talus, and this combines with the alluvium in the formation of a sloping apron of débris. In the case of the Wasatch range this tendency is partially counteracted by progressive movement along the great fault line which everywhere bounds the range. From time to time the mountain block rises, and the adjacent part of the valley block, with its load of detritus, sinks, and the height of the alluvial slope is thus diminished.

Near the Warm springs there is a point where the vertical rock face of the mountain is laid bare and the valley alluvium meets it as a horizontal plain instead of a foot slope. A few feet up the rock cliff a line of adhering cement marks former contact with the alluvium, the separation being presumably due to a recent fault. Near by, the alluvium is locally disposed in a series of steps marking details of displacement. A little farther northward between the Warm springs and the Hot springs, a symmetrical cone of alluvium is built upon the valley plain, and recent faulting has dropped one portion of this cone below another so that their relations can be clearly seen. The flood plain of the wet-weather stream descending the alluvial cone shows a series of terraces of different heights, illustrating the fact that the fault scarp was produced by a number of successive movements.

Garfield.—Garfield is a bathing resort on the shore of Great Salt lake, and will be visited in order to give members of the party an opportunity to bathe in the lake, and to examine the terraces and cliffs of Lake Bonneville.

The brine of the lake has a density at the present time of about 1·15, and its consequent buoyancy gives a new sensation to the bather. He readily floats, with head, feet, and hands out of the water. In swimming he is annoyed by the tendency of his feet to rise to the surface, and if he brings them beneath him so as to assume an erect position in the water, he finds not only his head but his shoulders above the surface.

The Oquirrh range is a mountain ridge rising several thousand feet above the plain and composed of Paleozoic rocks. At the northern end these are of Carboniferous limestones and quartzites. The range ends abruptly at the southern margin of the lake and its strata dip steeply toward the water. At low stages of Lake Bonneville it projected as a bold promontory, and at its northern face received the impact of waves generated in a broad sheet of water 1,000 feet (300 m.) in depth. As a result it is sculptured in the most elaborate and beautiful manner. Above the Bonneville level tower sea cliffs hundreds of feet in height. At the Provo level terraces hundreds of feet in width are carved from the limestone. At intermediate levels the face presents a succession of minor cliffs and terraces, and at lower levels near the shore of the modern lake are fossil beaches and spits of shingle. A climb of 600 feet (180 m.) to the Provo terrace will be repaid by a view of the phenomena of fossil shores such as can have few equals. [49]

Tooele valley.—Twenty miles west of the Oquirrh range the plain is interrupted by a similar ridge, the Aqui range, and this, too, ends abruptly at the shore of the lake. The lowland between the two mountain ridges is called Tooele valley at the north and Rush valley farther south. The two valleys are separated by a small cross range except at one point where a low pass connects them. Before the formation of Lake Bonneville Rush valley was drained northward to Tooele valley and traces of the drainage channel are still to be seen at the pass, but the waves and currents of Lake Bonneville transported an immense quantity of detritus to the pass and built across it a spit so massive that the waters of Rush valley have never been able to reopen the way. The Utah Western Railway will carry the party nearly to the northern base of this spit [49] and an opportunity will be afforded to walk or drive to and along its crest.

Little Cottonwood canyon.—The loftiest portion of the Wasatch range is about 20 miles (32 km.) south of Salt Lake city, and includes peaks rising 7,000 feet (2,100 m.) above the valley. Little Cottonwood is one of a group of creeks which head in this lofty region, course through deep gorges, and issue upon the plain below, where they become tributary to the Jordan river. In Pleistocene time the high mountain region gathered snows to form a dozen glaciers, and one of these, following Little Cottonwood canyon, protruded a short distance beyond its mouth, depositing lateral and terminal moraines of Alpine type. The ice foot was washed by the water of Lake Bonneville, and the terminal moraines were partly buried by delta deposits. The southern lateral moraine stands as a narrow embankment of typical form; the northern appears to have been afterward overriden by the ice, so that its material is spread into a low flat hill. The walls of the canyon at its mouth are of dark quartzite, but the moraines consist chiefly of white granite derived from

TROUGH PRODUCED BY FAULTING, NORTH OF MOUTH OF LITTLE COTTONWOOD CANYON.

the upper portion of the canyon. Their boulders have furnished the material for the Temple at Salt Lake City.

Just south of Little Cottonwood canyon a shallower valley called Dry Cottonwood descends the mountain face, and this, too, carried a Pleistocene glacier descending to the mountain base. The lateral moraines in this case coalesce with a massive terminal which the modern creek has notched but not yet divided.

Across the two pairs of lateral moraines and across the flood plains of the creeks runs a line of faulting characterized by the settling of great belts of earth. A portion of the north moraine of Little Cottonwood creek has dropped between parallel fault planes as much as 50 feet (15 m.), and this so recently that the escarpments are not yet covered by vegetation (Pl. VII). The longitudinal profiles of the other moraines, originally simple curves, have been made serrate, and the inner

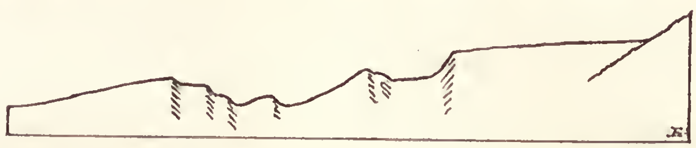


FIG. 20.—Profile of South Moraine at mouth of Little Cottonwood canyon.

faces of the moraines, originally smooth, have been furrowed and ridged in sympathy with the serrations. One of the fault-caused terraces of the northern flood plain has been utilized in the construction of an ore-smelting establishment. It is an impressive fact that the stream, a roaring torrent every spring, has not yet been able to reconstruct its dislocated flood plain.

We are here brought face to face with a process of mountain-making in actual progress. The Wasatch has grown perceptibly within a few years, and the gathering orogenic strains may culminate any day in another convulsive leap. It is a dictum of dynamic geology that great mountains are young mountains; [55] and the greatest of the mountains of the Salt Lake basin has not yet ceased to grow.

SALT LAKE CITY, UTAH, TO GRAND JUNCTION, COLORADO.

ITINERARY.

Station.	Distance.		Elevation.		Station.	Distance.		Elevation.	
	Miles.	Kilometers.	Feet.	Meters.		Miles.	Kilometers.	Feet.	Meters.
Salt Lake City[1]	0	......	4, 228	1, 289	Soldiers Summit	90	145	7, 465	2, 275
Francklyn	7	11	4, 291	1, 308	Pleasant Valley	98	158	7, 182	2, 189
Germania	10	16	4, 296	1, 309	Kyune	103	164	7, 052	2, 149
Bingham Junction	13	21	4, 366	1, 351	Castle Gate	112	180	6, 151	1, 926
Draper	17	27	4, 394	1, 339	Price	122	196	5, 547	1, 691
Jordan Narrows	23	37	....	....	Farnham	133	214	5, 534	1, 687
Lehi	29	46	4, 544	1, 385	Sunnyside	142	228	5, 270	1, 606
American Fork	32	51	4, 554	1, 388	Lower Crossing	161	259	4, 630	1, 411
Battle Creek	36	58	4, 497	1, 371	Desert	174	280	....	....
Provo	46	74	4, 517	1, 377	Sphinx	181	291	....	....
Springvile	51	82	4, 566	1, 392	Green River	187	304	4, 086	1, 226
Spanish Fork	55	88	4, 865	1, 483	Cisco	237	383	4, 447	1, 355
Castilla Springs	61	98	....	....	Agate	243	391	4, 425	1, 349
Thistle	66	106	5, 043	1, 537	Cottonwood	249	401	4, 602	1, 403
Red Narrows	72	116	5, 342	1, 689	Utah line	258	415	4, 661	1, 422
Mill Fork	77	124	5, 791	1, 765	Ruby	......	......	....	....
Clear Creek	84	135	6, 228	1, 898	Grand Junction	292	470	4, 560	1, 390

[1] Population, 44,843.

[By G. K. Gilbert.]

Leaving **Salt Lake city** in the morning the party resumes its journey, following the line of the Rio Grande Western Railroad through the valley of the Jordan, Utah valley, the canyons of Spanish fork and Soldiers fork, the valley of Price river, and the great monoclinal valley at the base of Book cliffs. For 75 miles southward from Salt Lake City the bold façade of the Wasatch range faces westward.

Twenty miles west of it lie smaller ranges, the Oquirrh, the Cedar, and the Tintic, and at its foot lie Jordan and Utah valleys. The Jordan valley is largely devoted to agriculture, but it contains also some of the principal establishments for the smelting of the silver ores of Utah.

The Jordan and Utah valleys are separated from one another by spurs of volcanic rock, stretching from the Wasatch and Oquirrh ranges until they nearly meet. The narrow pass between their extremities is occupied by the Jordan river, whose bank the railroad follows. In

Bonneville times the eastern spur was exposed to an energetic attack of waves from the north. A deep notch was cut in its side, producing a cliff hundreds of feet in height, and the material excavated was piled as a spit of shingle in the pass, partially closing it. As the train moves up the Jordan valley the shore terrace and the sea cliff can be seen from a distance, and, as it threads the pass, the gravels of the spit appear near at hand. In the pass are the headworks for the diversion of the Jordan water into canals for the irrigation of the valley.

The mountains towering above Utah valley are of wonderful boldness and beauty, and their precipitous faces are such as result from no orogenic process save that of faulting. Back of the visible mountain crests are extensive uplands, serving as a gathering ground for the streams which here and there break through the main ridge in defiles and fertilize the valley. Their waters are finally gathered in Utah lake, from which the Jordan river issues, flowing, like that other Jordan after which it is named, from a lake teeming with life to a sea of death.

The Bonneville and Provo shore lines are to be seen all about the valley, and the Provo shore line is characterized by numerous delta terraces. The delta of the Provo river has a radius of more than 4 miles (7 km.), and crowds the railroad close to the lake. Along the mountain base and across the delta terraces run fault scarps, occasionally giving one of the shore lines a sudden change of altitude.

The two sides of the valley are in striking contrast. The eastern, receiving the drainage of the lofty Wasatch, enjoys the condition essential to fertility in an arid region, and is dotted with thriving villages: **Lehi, American Fork, Battle Creek, Provo, Springville,** and **Spanish Fork** are passed by the train. On the west, the low ridge called Cedar mountain induces little precipitation and possesses no permanent stream. Even springs are lacking, and its slopes, clothed only by a scant growth of low bushes, sustain no human home.

Due east of **Provo** the face of the Wasatch is unusually steep, rising in a slope of nearly 35° to Provo peaks, and presenting a remarkable section of Paleozoic rocks over 10,000 feet in thickness, from Cambrian up to Middle Carboniferous, resting on crystalline schists, of which a small exposure is found at the very base of the slopes. These beds all dip eastward, at first very steeply, but with decreasing angle to the east.

Hobble creek, which waters the town of **Springville**, built a broad delta at the level of the Provo shore line. The Spanish fork, as the next stream is called, built a still broader delta at the same level, and the two are confluent. The Spanish fork built one also at the Bonneville level with a radius of 4,000 feet (1.2 km.). This was widely trenched during the building of the lower delta, so that the head of the lower lies within a gorge excavated from the upper. Both deltas are

profoundly dislocated, the zone of faulting being a mile wide, but many of the faults traverse the upper delta only, showing that the lake epoch, like the recent epoch, witnessed mountain growth. The train, on its way from **Springville** to Spanish Fork canyon, climbs and crosses the contluent lower terrace and traverses the district of faults.

[By S. F. Emmons.]

In Spanish Fork canyon the main Wasatch uplift is crossed in a southeasterly direction at a point where it is much narrower than in either of the transverse gorges further north. No systematic geological examination of this portion of the range has yet been made, and only the broader outlines of its structure can be given.

About 6,000 feet (1,829 m.) of Upper Paleozoic beds, mainly siliceous members of the Upper Carboniferous, are first crossed, which dip 25° to 30° to the southeast. These form the main front range through which the Spanish Fork gorge is cut. Overlying these and generally with somewhat steeper dip, are conglomerates, shales, and red sandstones, presumably of Triassic age. Two streams, running in monoclinal valleys eroded out of these rocks, unite to form that of Spanish Fork. Beyond the junction the road bends to the south up the valley of one of the streams, known as Thistle Creek. On the east side of this valley are fine cliff exposures of the characteristic red sandstones of the Trias, overlain by massive yellowish white sandstones, remarkable for their cross-bedding and the curious forms into which they weather in the overhanging cliffs. The estimated thickness of these rocks above the Carboniferous is 4,000 feet (1,219 m.).[56] A branch line follows this valley southward to the Mormon towns in the San Pete and Sevier valleys.

The main line at **Thistle** bends eastward, across the strike of the beds, up the valley of Soldiers' Fork. A short distance beyond this station are seen the drab shales and thin-bedded limestones of the Jurassic, resting in apparent conformity on the cross-bedded sandstones, in which, along the railroad cut, may be found Pectens and *Pentacrinus Asteriscus.* Ascending the valley of Soldiers' Fork the upturned edges of the Jurassic strata are covered by nearly horizontal beds of reddish conglomerates and coarse sandstones which, in geological position, composition and manner of weathering, resemble those of the Wasatch Eocene, as exposed in Echo canyon along the line of the Union Pacific Railroad. After ascending for some miles past the castellated cliffs formed by those conglomerates, an overlying series of light-colored calcareous marls and shales is reached, which are less massive, and probably represent the Green River Eocene of the Wyoming Basin, since they are said to rest unconformably on the conglomerates and to overlap on to the upturned Jurassic and Triassic strata nearer the mountains.

SAN RAFAEL SWELL.

The road ascends rapidly through these Tertiary beds, the gradient, in the last 7 miles (11 km.) before reaching **Soldiers Summit**, being 3¾ per cent, or 200 feet (61 m.) to the mile (1.61 km.).

Soldiers Summit is at the crest of the Tertiary watershed, which lies from 20 to 40 miles (32 to 64 km.) to the east of the crest of the Wasatch range. The road now descends the valley of Price river nearly to the Colorado river, through a region of almost horizontal Mesozoic and Tertiary beds which are uninfluenced by the Wasatch upheaval. This region is not only of modern geological formation, in that it is traversed by no known lines of long continued dynamic movement, and hence owes its topographical form entirely to erosion, but its erosion is of the type peculiar to an arid or practically rainless region whose streams are fed only by the precipitation on high areas outside of the region. This erosion is produced primarily by the streams in their narrow beds, whose winding course was first determined on a comparatively level surface of unconsolidated and easily abraded beds. The first characteristic of such a drainage system, as distinguished from one that is built up on the drainage systems of earlier geological periods, is its comparative independence of the obstacles opposed to its course by the relative hardness, or the position of older strata, which it has reached after cutting its bed down through the uniform and softer overlying strata. This produces the effect designated "inconsequent drainage."

From **Pleasant Valley** a branch runs southward up the main fork of Price river to the coal mines in the Laramie Cretaceous at Scofield. In the reddish beds about a mile (1.61 km.) north of **Pleasant Valley** station are found veins of ozocerite or mineral wax. This and allied hydrocarbons are found abundantly in the beds of the Green River Eocene at various points in the basin region between the Wasatch and the Rocky mountains. A gray limestone near the station contains fresh water mollusks, which may prove to belong to this period.

The road descends rapidly in geological horizon, as well as topographically, and in a few miles enters the massive gray sandstones of the Laramie Cretaceous, in which Price river has cut a narrow, winding, and ever-deepening gorge, whose walls show a great variety of castellated forms due to erosion. The finest of these is just above **Castlegate**, where a narrow column of sandstone, over 500 feet (152 m.) high, stands at the end of a sharp, narrow ridge like the watch-tower of a castle.

At **Castlegate** is a coal mine with coke ovens, which obtains coal from a seam near the base of these massive sandstones.

As the road descends below the coal horizon of the Laramie, through the more thinly bedded sandstones of the Fox Hills formation which contain an ever-increasing proportion of clay shales, into the readily

eroded clay beds below, the sandstones are left behind forming in curving lines of precipitous cliffs on either side.

At **Price** the road emerges into the great open monoclinal valley in the clays of the Middle Cretaceous, which extends eastward to and beyond **Grand Junction**, a distance of nearly 200 miles (322 km.). The Laramie sandstones, dipping gently 7° to 10° north, retreat to the northward, and gradually merge into the great mural escarpment of the Roan or Book cliffs, which, with an average height of over 2,000 feet (610 m.), stretch entirely across the Colorado basin, in a curve convex to the south, connecting the plateau system on the east flank of the Wasatch uplift with that on the west of the Rocky Mountain system of Colorado. Through this whole distance the Laramie Cretaceous forms a continuous outcrop. Above it, sometimes forming second lines of cliffs at a little distance back, and sometimes capping the main escarpment, rest successively the coarse reddish or roan-colored sandstones of the Wasatch Eocene, and the drab calcareous shales of the Green River Eocene. The latter are characterized by the thinness of their strata and the great definition of their bedding lines, so that their cliffs resemble the leaves of a book, whence the name "Book Cliffs." Throughout the interior of the basin these Eocene beds rest in parallel transgression upon the Laramie Cretaceous, but along its periphery, especially on the flanks of the Uinta mountains, which form its northern border, they overlap its upturned edges, high up on the flanks of the range, to a contact with Jurassic, Triassic, and even Carboniferous rocks.

The erosion which has formed these cliffs is peculiar to a practically rainless region surrounded, as is the Colorado basin, by high mountain masses. It is produced by the undermining of rock faces in the softer strata beneath by sudden floods, resulting from violent showers, popularly known as cloud-bursts, starting at long intervals and under favorable meteorological conditions from the surrounding elevated regions and spreading out locally over different portions of the arid basin region. These in a few moments change dry stream beds into boiling, muddy torrents, which carry away an enormous amount of material that dry disintegration, aided by great diurnal variations of temperature, had already loosened. Thus the Book cliffs, which, owing to the northerly dip of their component strata, are eroded almost entirely on their southern face, have retreated most rapidly at either extremity, owing to its proximity to the mountains, and now stand in a curve convex to the south, which in the center of the basin is 40 miles (64 km.) farther south than its western end.

The Cretaceous in this region consists of a series of peculiarly resisting quartzitic sandstones (Dakota) at the base, succeeded by several thousand feet of clay shales, with a few thin sandstones and limestones,

all of marine formation, and capped by the massive sandstones and shales of the coal-bearing Laramie. The monoclinal valley followed by the road shows well the peculiar topography which everywhere characterizes wide exposures of these Middle Cretaceous shales.

At **Lower Crossing** may be observed an interesting example of inconsequent drainage, where the Price river leaves the wide, open valley in the soft clays and boldly cuts its way in a deep gorge through the Book cliffs, in an easterly direction, to the Green river, which it reaches 16 miles (26 km.) above the railroad crossing.

The road now rises slightly before descending into the valley of Green river, and from favorable points one can see, far to the south, remarkable castellated forms of erosion in harder beds of the lower portion of the Mesozoic, brought up by the monoclinal uplift of the San Rafael swell (Plate VIII). In clear weather a glimpse may also be had, on the distant southern horizon, of the sharp laccolitic peaks of the Henry mountains.

Back of **Green River** station is a mound of dark shales, probably belonging to the horizon known as Fort Benton Cretaceous, which abounds in fish remains and inocerami.

Green river, which is crossed at a point where but little can be seen of its characteristic canyon scenery, is the main tributary of the Colorado river of the West. It takes its rise nearly 300 miles (483 km.) due north of the crossing, in the Wind River mountains, and flowing south across the interior Tertiary basin of Wyoming, famous for its vertebrate remains, it cuts through the heart of the Uinta mountains in a series of deep, winding gorges carved out of the very hardest siliceous rocks. It then flows south through the Colorado basin, and about 60 miles (97 km.) below the crossing is joined by the Grand river, which drains the western slopes of the Rocky mountains. It is only after the confluence of the latter stream that it is called the Colorado river.

In the vicinity of Green river, and especially on the east side, the characteristic scenery of the Cretaceous shales is most marked, the country being absolutely bare of vegetation of any kind for long distances. The stations in this region are appropriately named **Desert**, **Sphinx**, **Solitude**, etc. The accompanying sketch (Fig. 21) of the latter was made from the train by Mr. Cadell.

The Valley of Desolation in these shales is followed for 50 miles (80 km.) east of Green river. The road gradually rises over low divides, being at times more than a thousand feet (305 m.) above Green river, and then descends into the valley of Grand River. In clear weather fine views are had, from elevated points, of the laccolitic group of peaks lying 30 miles (48 km.) to the south and east, known as the Sierra la Sal, [57] whose summits have elevations of 12,000 to 13,000 feet (3,658 to 3,962 m.).

At **Cisco** an artesian well has a considerable flow of water, the surplus

of which, over and above that used by the railroad, has has been utilized for irrigation, but as yet without much beneficial effect upon the clayey soil.

Between this station and **Agate** the northwesterly dipping sandstones of the Dakota Cretaceous are crossed, and the railroad then descends through variegated clays and sandstones of the Jurassic into the thin-bedded sandstones of the Trias, which it reaches at the Grand river.

The road now runs for over 15 miles (24 km.) along the banks of the river, following its winding canyon gorge, cut in the massive sandstones of the Trias, which form the northern edge of the great Uncompahgre plateau. This plateau is an area extending 80 to 100 miles (129 to 161

FIG. 21.—Solitude Station.

km.) northwest from the base of the San Juan mountains, of nearly horizontal or gently folded strata of Lower Mesozoic and Upper Paleozoic age resting unconformably upon Archean granites and gneisses. The latter rocks are only exposed in the bottom of some of the many canyon gorges which intersect the plateau. The northern edge of the plateau is formed by an abrupt monoclinal fold, along which the strata bend down so abruptly that they seem to be faulted. The canyon is cut mainly in the massive and nearly horizontal sandstones on the north side of this fold, but at times in its meanderings discloses views of the fold itself.

Going east, after reaching the valley of the Grand, the more massive beds of the Trias slowly rise from beneath the thinner beds at the top. They present on the north of the road magnificent walls formed by vertical cleavage planes and which show fine examples of cross-bedding.

At **Utah line** the boundary between Utah and Colorado is marked by a white line running up the face of the cliff.

A few miles further east, after passing round a northward projecting point of the cliffs, one can distinguish along the banks of the river and projecting above its surface in midstream, rounded knobs of Archean rocks, blackened, polished, and singularly channeled by the action of the water. These rocks form apparently an east and west ridge in the line of the monoclinal fold, which the road now follows for some distance on a tangent.

Just before reaching **Ruby** an excellent section of the monoclinal fold may be seen on the north side of the river, where a small tributary ravine is cut along its axis.

The road now passes beyond the fold into the gray sandstones and intercalated shales of the Jurassic and Dakota Cretaceous, in which the effects of undermining by the action of the stream are well displayed. It soon leaves the valley of the Grand river, passing up a tributary ravine, through a tunnel in Dakota sandstone, and out on to the broad valley of Cretaceous shales again. Twelve miles (19 km.) distant, forming the southern boundary of this valley, are the Little Book cliffs,[58] the eastern continuation of the line of cliffs which has been followed from Utah. It is formed here entirely of Cretaceous beds, the overlying Tertiary beds forming a second line of cliffs further back, trending to the northeast, for all the beds are now commencing to rise to the east on the west flanks of the Rocky mountains.

The clay valley is followed to **Grand Junction**, a growing town that is now becoming prominent for the excellent quality of its fruits which have been raised by its citizens on the neighboring mesas under the beneficent influence of irrigation.

THE ROCKY MOUNTAINS OF COLORADO.

By S. F. Emmons.

Upon leaving Grand Junction the route passes from the basin of the Colorado river into the Rocky mountain region, or, according to Powell's and Gilbert's nomenclature, from the Plateau region into the Park province. The name "Rocky Mountains" has been retained for this most eastern and most elevated group of mountain ranges of the Cordilleran system, because it was the one which was first seen by early explorers after their weary journeys across the Great Plains, and is therefore the one to which the name was first applied. It was called the Park province from its great interior valleys, entirely closed in by mountain ridges, which constituted the natural game preserves of the various Indian tribes that formerly inhabited the surrounding lowlands.

The route chosen for the party does not traverse any of the greater of these parks or valleys, but follows the deeper and narrower drainage channels of more modern date, from whose fresher excavations and cuts the geologists may more readily obtain by a passing glance an insight into the internal structure of the region than he could from the older, gentler, and more covered slopes of the parks. A description of the region proceeds naturally from the east westward, rather than in the direction by which it will be approached by the present party, since on the eastern side its characteristic features are more strongly and distinctly marked. While the general physiographical features of the group as a whole arrange themselves along north and south lines, the prevailing northwest and southeast trend of the Cordilleran system is manifested in many details of the topography, as it is in the internal geological structure.

The eastern front of the group, facing the Great Plains, is formed by the Colorado or Front range from the northern boundary of Colorado south to Pueblo, a distance of about 200 miles. Further south it is formed by the Wet Mountain and the Sangre de Cristo ranges, set off successively a little to the west of each other *en echelon*, and separated by northwest-trending indentations or bays.

Back or to the west of these come the Parks—the North, Middle, and South Parks, lying opposite the Colorado range; Wet Mountain valley, on the flanks of the mountains of the same name, and San Luis park, stretching along the western foot of the Sangre de Cristo range, whose culminating point, Blanca Peak, is the highest mountain in Colorado.

The western wall of the North and Middle parks is formed by a sin-

gle chain known as the Park range; opposite the South Park this is represented by the double elevation of the Mosquito and Sawatch ranges, which in earlier geological time formed a single massive, but are now separated by the great meridional valley of the Upper Arkansas. To the south these two ranges coalesce in the single ridge of the Sangre de Cristo range, which trends first to the southeast, dividing Wet Mountain valley from San Luis park, then southward forming the eastern front of the whole group, and finally disappears beneath the desert plains of New Mexico.

The westernmost tier of mountain uplifts, which is still more broken and irregular, is constituted by the White Mountain plateau, on the north, opposite the Park range; the complicated and lofty group of the Elk mountains, which adjoin the western flanks of the Sawatch uplift; and to the south, separated from the latter by the broad mesa slopes of the Gunnison valley, are the San Juan mountains, stretching westward from the San Luis park to the Uncompaghre plateau.

With the exception of Middle and San Luis parks, all the interior valleys send their waters across or around the component parts of the Front range into the Mississippi valley; the outlet of San Luis park is southward through New Mexico into the Gulf of Mexico; Middle park is drained by the Grand river, which threads its way in deep narrow gorges, between the White River plateau on the north and the Sawatch and Elk mountains on the south, to the Colorado river.

The geological structure of these different mountain masses is, as a rule, very complicated, but as the study of the region progresses it becomes more and more evident that its broad general features must have been outlined at very early dates in its geological history. In each of the great mountain masses are found representatives of the Archean, Paleozoic, and Mesozoic groups. In but few have Algonkian beds yet been recognized. Eruptive rocks of different ages are found in all, but the greater manifestations of eruptive activity, in Tertiary times, have occurred mainly in the southern and western portions of the region.

Five great transgressions, indicating as many orographic[59,60] movements, have thus far been recognized, and future study may disclose others. These are: The post-Archean, the post-Algonkian, the late-Paleozoic, the late-Jurassic, the post-Cretaceous. Minor movements undoubtedly occurred in Tertiary times, as in the Wasatch region, whose general effect has been to raise the whole group, and to compensate for the degradation produced by erosion.

In the middle belt, which is traversed by the party and may be taken as a type of the structure of the whole group, the central uplift is formed by the Sawatch massive, a great oval area of Archean rocks, surrounded by an almost completely encircling fringe of Paleozoic and

Mesozoic beds dipping away from it at various angles. These beds give internal evidence of having been deposited around a land mass, and from their present position it is evident that the central Archean area was never completly covered by them. They also show little or no discrepancy in their angle of dip.

The Elk mountain massive, which lies immediately to the west of the Sawatch, is a region of intense disturbance. The sedimentary beds are profoundly plicated and faulted; and, though the peaks are as high as those of the Sawatch, and the intermediate valleys even more profoundly eroded, only an extremely limited area of Archean is exposed. Many of the higher peaks are immense masses of diorite, up to 15 miles in diameter, which have been protruded through the sedimentary beds during the post-Cretaceous movement. The evidence of the various transgressions, which is remarkably distinct in these mountains, is found in discrepancies of strike rather than of dip. Thus, where the upturned sedimentary series is crossed by the train, on the Grand river above Newcastle, the strata seem perfectly conformable from Laramie Cretaceous down to Cambrian. Yet the sandstone series of the Dakota Cretaceous (which includes also some beds of probable late Jurassic age, hence sometimes called Jura-Dakota sandstones), if followed southward along their strike into the Elk mountains, would be found to rest on successively lower beds from Paleozoic to Archean. Besides the diorite masses in the more disturbed central region, numerous picturesque mountain masses are formed by laccolites of quartz-porphyry in the nearly horizontal Cretaceous strata of the southern and western portion of this remarkable group of mountains. On the east, between the Elk mountains and the Sawatch. is a zone of profound faulting, following north and south lines.

To the east of the Sawatch mountains, and separated from them by the great longitudinal valley of the Upper Arkansas, lies the Mosquito or Park range, which once formed an integral part of the Sawatch and has been uplifted into its present position by plication and faulting, which was initiated during the late Jurassic movement. The fault follows a north and south line just west of the main crest, and has been traced for over 50 miles. The Upper Arkansas valley is thus a comparatively modern topographical feature.

The wide valley of South park, on the other hand, which lies between the Mosquito range and the broad Archean mass of the Front or Colorado range, is underlaid by the beds of the entire Mesozoic and Paleozoic groups, which descend with decreasing angle of dip from the crest of the former and disappear beneath the recent beds which form its present floor. They are probably cut off by a fault on its eastern edge, but this does not appear farther south, on the line traversed by the train along the valley of the Lower Arkansas.

On the eastern flanks of the Colorado or Front range the Paleozoic and earlier Mesozoic beds appear only in disconnected patches, being covered in the intermediate portions by beds deposited during the late Jurassic, post-Cretaceous, and Tertiary transgressions. A narrow zone of sharply-upturned beds, mostly of Mesozoic age, is generally found at the immediate base of the mountains, the harder beds forming narrow monoclinal ridges called "Hogbacks," which are separated from the main mountain slopes by longitudinal valleys eroded out of the softer beds of the series. These sharply-upturned beds, whose angles of dip are as high as 60° or 70°, change sharply to an approximately horizontal position in very short distances east of the mountain foot. In some cases the outer or upper beds of the upturned series stand at a steeper angle than those below, or nearer the Archean base, producing thus a partial fan structure. The overlying Tertiary beds sometimes partake to a limited extent in the upward curve of the underlying Mesozoic strata, thus evidencing a comparatively recent movement of uplift of the mountain mass, or a sinking of the plain area.

The coal-bearing beds of the Laramie Cretaceous, which were deposited as the ocean waters were finally leaving the western United States, spread not only over all the Great Plain areas around the mountain groups but also over many of its interior valleys. These beds being the first of the series to be acted on by the forces of erosion, have been removed from considerable areas that they once covered, especially along the eastern portion of the Great plains and the southern portion of the Colorado basin. In other areas they have been deeply buried beneath succeeding deposits of Tertiary age. In spite of these facts, the available coal-bearing areas that still remain are of enormous extent, and already play an important part in the industry of the region. The Census reports for 1890 show that in that year the coal mines of Colorado produced 2,360,000 tons of coal and gave employment to 4,645 persons. The coal varies in character from a rather light, dry, porous coal, with high percentage of water and of volatile matter, to fairly dense caking or coking coal. The latter coals are generally found to the south and west, in regions where eruptive rocks abound. In the southwestern Elk mountains, moreover, are beds of excellent anthracite.

The aggregate thickness of the various geological series has, as a rule, very materially decreased from that shown in the Wasatch region. A greater mass of Archean is shown because it has been more deeply eroded. The Ouray beds (assumed to be Algonkian) of the San Juan mountains are over 10,000 feet thick. On the other hand, but a few hundred feet of Paleozoic beds below the Carboniferous are found, the lower members of the Cambrian and the entire Devonian being apparently unrepresented. The Carboniferous series is the most generously developed of any in the Paleozoic group, but this averages only about

5,000 feet, as against 15,000 feet in the Wasatch. The various members of the Mesozoic have a wide range of local variation in thickness, but it is always less than that of corresponding horizons in the Wasatch. The marine Jurassic of the Wasatch is apparently wanting, as is the Lower Cretaceous of Texas and British Columbia. The age of many of the disconnected Tertiary deposits has not yet been determined, though Eocene and Pliocene and probably Miocene are represented.

GRAND JUNCTION TO GLENWOOD SPRINGS.

By S. F. EMMONS.

Station.	Distance.		Elevation.		Station.	Distance.		Elevation.	
	Miles.	Kilometers.	Feet.	Meters		Miles.	Kilometers.	Feet.	Meters.
Grand Junction ..	0	0	4,560	1,390	Rifle..............	63	101	....	....
Palisades.........	12	19	....	....	Newcastle........	77	124	5,555	1,693
De Beque.........	33	53	....	....	Chacra	81	130	....	....
Parachute........	46	74	....	....	Glenwood.........	89	143	5,767	1,758

From **Grand Junction** the road goes northward for 15 miles (24 km.) across the clay plains to the mouth of Hogback canyon. On the east may be seen the line of the Book cliffs continued in those of Grand mesa, a high plateau formed of basalt, capping Wasatch and Green River Eocene beds.

Hogback canyon, above **Palisade** station, is cut in the heavy gray sandstones of the Laramie Cretaceous, which dip gently north and west, so that higher horizons are constantly coming in view. The canyon shows fine cliff sculpture and excellent instances of the erosion due to undermining, which is peculiar to the Colorado basin or Plateau province. In one case the ruins of a spur of Laramie sandstone, which had been undermined on either side, are piled up along the valley in huge broken masses over a quarter of a mile in width and nearly a mile in length.

Beyond the canyon a broad alluvial valley opens out, from which, just before reaching **Debeque** station, can be seen, to the northwest, the main Book cliffs, which rise 3,000 feet (914 m.) above the river, formed of the massive roan-colored beds of the Wasatch Eocene, capped by the thinly stratified, shaly beds of the Green River Eocene. The latter contain abundant fish remains, and, in consequence, much bituminous matter, some of the shales being so rich in hydrocarbons that they may be ignited by a match. Deposits of an asphaltum mineral, Uintaite or Grahamite, are found in considerable quantities at various points. On the east may be distinguished the Mam mountains (11,000 feet, 3,353 m.), twin peaks of basalt capping Green River beds.

Of the streams entering the Grand river from the north, Roan and Parachute creeks drain the interior of the Book plateau, but Rifle creek drains the monoclinal valley within the Hogback ridge of Laramie sandstones which forms a semicircle around the west flanks of the great White River plateau, breaking through this ridge in a narrow gorge six

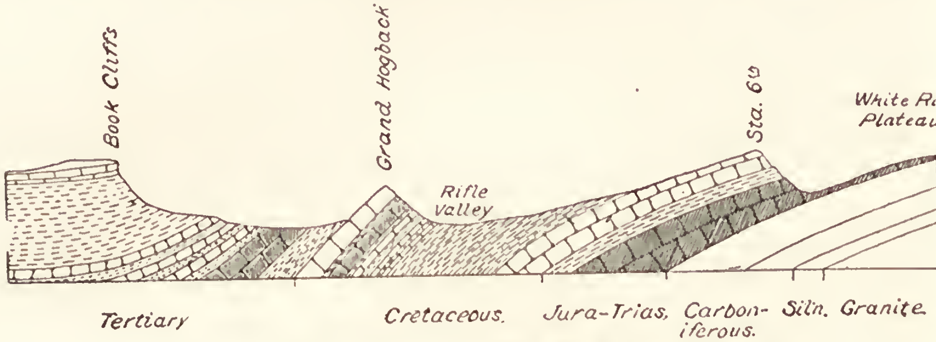


FIG. 22.—Section from Book cliffs to White River plateau. [58]

miles (10 km.) due north of **Rifle** station. This great Hogback ridge, which here rises 2,000 feet (610 m.) above the valley level, can be traced, almost continuously, northward along the west flanks of the Elk mountains, then bending in a curve around the White River plateau to White river, and then westward along the southern flanks of the Uinta mountain uplift to the Wasatch, a distance of about 250 miles (402 km.). According to Mr. R. C. Hills, who has made a special study of the coal-bearing beds, the Wasatch Eocene is also upturned on the flanks of this ridge, whence he reasons that the Eocene movement (post-Bridger) played an important part in the Rocky mountain uplift. [60]

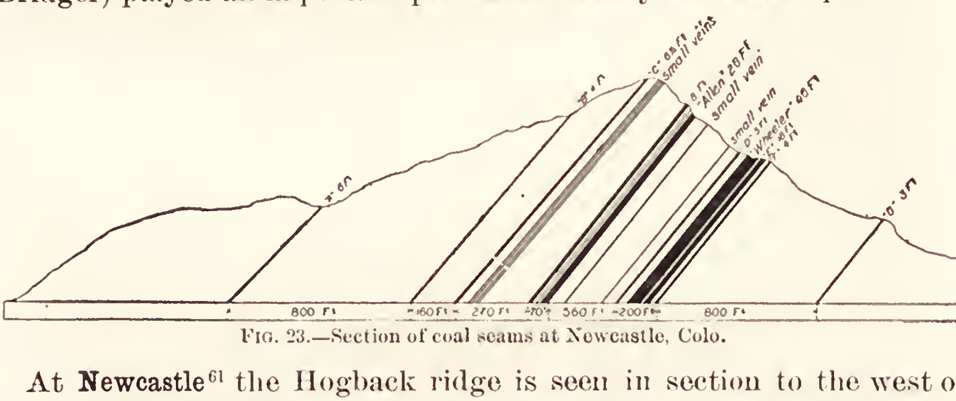


FIG. 23.—Section of coal seams at Newcastle, Colo.

At **Newcastle**[61] the Hogback ridge is seen in section to the west of the town, where coal mines are opened on some of the numerous coal veins, which contain an aggregate thickness of over 125 feet of coal. These are shown in the cross section (Fig. 23), furnished by the manager of the mines, Mr. W. B. Devereux.

About 2 miles (3 km.) south of the town, the great 45-foot vein has been burning for ages deep down beneath the surface. At many other

points, the baked and reddened rocks along the outcrops show that coal seams have been similarly consumed near the surface. From **Coal Bridge** station, a short distance beyond **Newcastle**, an inclined tramway can be seen on the east side of the river, which brings coal down from seams in the Laramie sandstones high up on the steep northern face of the ridge.* These mines belong to the Elk Mountain Fuel Company.

The monoclinal valley of Elk creek, which enters the Grand river from the northwest at **Newcastle**, is cut in the clayey beds between the sandstones of the Laramie above, and the Dakota-Jura below. Some of these are shown in section in a railroad cut on the west side of the river above **Newcastle**. The valley of the Grand, which is here crossing the beds, bends to the southeast when it reaches the Triassic sandstones, following them irregularly with and diagonally across the strike for about five miles (8 km.), and then, at **South Canyon** station, bending again across the strike in a narrow gorge, comes out into a more open valley eroded out of the shaly limestones and gypsiferous beds of the Upper Carboniferous, which it follows eastward to **Glenwood Springs**.

The sedimentary beds are here all upturned against the southwestern flanks of the White River plateau, which is an elevated area of Paleozoic rocks resting on Archean and capped by flows of basalt. It is nearly circular in shape, 30 to 40 miles (48 to 64 km.) in extent and 10,000 to 13,000 feet (3,048 to 3,962 m.) above sea level. It is almost completely surrounded by an encircling fringe of Mesozoic beds (for the most part steeply upturned in monoclinal folds), some and probably all of which once covered the plateau, but were eroded away before the outpouring of the basalt.

The pretty town of **Glenwood Springs** is situated at the mouth of the Roaring Fork, an important stream flowing southwest from its sources on the west slopes of the Sawatch range, and on the south bank of the Grand river, which has a general southwest course from its head in the Middle park. It is also at the junction of two important lines of railway, the Colorado Midland, which after crossing the summit of the Sawatch range descends the valley of the Roaring Fork, and the Denver and Rio Grande, which comes down the valley of Eagle and Grand rivers. Its owes its importance in no less degree to its thermal springs and fine bathing establishment.

The springs issue from the Lower Carboniferous limestones which here dip southward away from the flanks of the White River plateau, while the open valley of the Roaring Fork above the town, and that

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* On the maps of the Hayden Geological Atlas of Colorado, the color of the Fox Hill Cretaceous is spread over many areas on the west flanks of the mountains which have since been proved to be true coal-bearing Laramie.

of Grand river for a few miles below, are eroded out of the overlying softer, gypsiferous beds of the Carboniferous. The latter can be seen in section by following up a steep narrow ravine, directly east of the town, which is cut in the flanks of a basalt-capped plateau of Triassic and Carboniferous rocks. The harder limestones and quartzites of the Lower Paleozoic may be well seen by following the Denver and Rio Grande Railroad a mile or two above the town through the first tunnel, beyond which the Cambrian quartzites rest on the Archean.

The bathing establishment is on an island in the river opposite the town, and consists of handsomely appointed bath buildings, back of which is an open-air bathing pool of masonry, nearly 700 feet (213 m.) long, at one end of which a stream of hot water from the springs* is constantly pouring in, while at the other is a fountain of cold mountain water, so that the bather can find any desired temperature. There is also a natural steam bath, arranged in a cave in the limestone on the south bank of the river just above the town.

From the hill slopes on the north side of the river, opposite the town, a beautiful distant view may be had, up the Roaring Fork valley, of the snow-capped Sopris Peak, 12,823 feet (3,600 m), one of the great diorite masses breaking up through much disturbed Paleozoic strata, which are a characteristic feature of the Elk mountains.

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* *Analyses of Glenwood Spring water in grains per United States gallon.*

[By C. F. Chandler, PH. D.]

	Yampa spring.	Unnamed spring.		Yampa spring.	Unnamed spring.
Chloride of sodium	1,089·8307	1,086·9449	Bicarbonate of iron	Trace.	Trace.
Chloride of magnesium	13·0994	13·4011	Phosphate of soda	Trace.	Trace.
Bromide of sodium	0·5635	0·8203	Biborate of soda	Trace.	Trace.
Iodide of sodium	Trace.	Trace.	Alumina	Trace.	Trace.
Fluoride of calcium	Trace.	Trace.	Silica	1·9712	2·0119
Sulphate of potash	24·0434	24·5971	Organic matter	Trace.	Trace.
Sulphate of lime	82·3861	80·2499	Total	1,250·0411	1,243·4303
Bicarbonate of lithia	0·2209	0·2872			
Bicarbonate of magnesia	13·5532	13·7634	Temperature	124·2° F.	124·2° F.
Bicarbonate of lime	24·3727	21·3545			

GLENWOOD SPRINGS TO ASPEN.

ITINERARY.

By S. F. Emmons.

Station.	Distance.		Elevation.		Station.	Distance.		Elevation.	
	Miles.	Kilometers.	Feet.	Meters.		Miles.	Kilometers.	Feet.	Meters.
Glenwood	....	....	5,743	1,750	Aspen Junction	24	39	6,585	2,007
Cardiff	4	6	5,925	1,806	Watson	32	51	....	....
Sands	....	....	6,081	1,853	Rathbone	36	58	7,653	2,333
Wheeler	18	29	6,357	1,937	Maroon	40	64	....	....
Sherman	....	....	....	....	Aspen	42	68	7,935	2,419

The valley of Roaring Fork, for some distance south of Glenwood, is an anticlinal valley. That is, the bounding ridges on the west have the western dip of the upturned fringe of beds along the western flank of the Rocky Mountain uplift, while in the hills on the east the beds have a slight dip east toward the triangular synclinal area included between the Elk mountains, the Sawatch range, and the White River plateau. For the first part of the way the valley bottom is in the softer beds of probable Carboniferous age, immediately underlying the red sandstones of the Trias, which are seen in the hills on either side. The valley contains a great amount of glacial débris, often arranged in flood-plain terraces, and increasing toward the upper part of the valley.

At **Cardiff** station are extensive coke ovens. Here a short branch line comes in from the west which brings coal from large mines at Sunshine and Jerome Park, in a monoclinal valley in Cretaceous strata beyond and parallel to the ridge bounding Roaring Fork valley on the west.

About 12 miles (19 km.) from **Glenwood** the valley forks, Rock creek coming in from the north to join Roaring Fork. From here one has an uninterrupted view of Sopris Peak, which lies between these two streams. The general structure of the peak,[62] with the sedimentary beds sharply upturned around the dioritic core, can readily be distinguished in clear weather, and in the distance, up Rock Creek valley, one can see the high summits of the Ragged Mountain group, composed of laccolitic bodies of porphyry intruded into Cretaceous strata.

All the way up the valley of Roaring Fork, above Rock Creek, occasional glimpses are obtained over the intervening ridges, of the grace-

ful summit of Sopris, which is most beautiful in the spring and autumn when it is freshly covered with snow.

For about 12 miles (19 km.) above Rock Creek the valley bottom is still in soft Upper Carboniferous beds, somewhat faulted and contorted, but in general occupying a gentle anticline between the synclinal fold on the west, at the east base of Sopris, and the triangular syncline to the eastward already mentioned. The latter has been considerably eroded and subsequently covered with basalt flows, parts of which still cover the higher flat-topped ridges, and their débris may be distinguished on the east side of the valley, mingled with that of the red sandstones which form the bounding cliffs.

On the west side of the valley the lighter-colored Jurassic beds may be distinguished above the red sandstones, which now come down to the valley bottom with a westerly dip.

At **Aspen Junction** the main line of the Colorado Midland leaves the Roaring Fork valley and follows up that of Frying Pan creek in an easterly direction. For many miles above the junction this line follows a winding gorge cut in red sandstones of Triassic and Upper Carboniferous age, which present grand cliff exposures. Beyond these it passes along more open valleys cut in Lower Paleozoic limestones and quartzites, and finally reaches the Archean granite and gneiss which forms the core of the Sawatch range. A long tunnel in these rocks, under the crest of the range, is mainly in granite.

In the Roaring Fork valley, above **Aspen Junction**, the railroad follows a flood-plain bench through a widening of the valley, and then passes through narrows formed by red sandstones, massive below, thin-bedded and lighter-colored above. The structure is here somewhat complicated, showing sharp folds and some faulting. In general the route now lies along the eastern side of a synclinal in Cretaceous and Jurassic beds, the northern continuation of the synclinal fold, already mentioned as formed by the uplift around Sopris Peak. The beds are mostly argillaceous shales with some impure limestones. On the east side of a second widening of the valley, which shows considerable flood-plain terraces, is the mouth of Woody creek, another tributary draining the west slopes of the Sawatch.

The road now passes along the strike of the westerly dipping Cretaceous shales and limestones, the hills on the east being formed of underlying red sandstones, while on the west the sharp synclinal fold can be distinguished in a harder limestone bed (probably Niobrara Cretaceous).

Just before reaching **Aspen** a flood-plain terrace is crossed between Maroon and Castle creeks, up whose valleys, to the west and north respectively, distant glimpses may be had of the castellated forms around Maroon and Pyramid peaks in the Elk Mountains.

The valley gorge of Maroon creek is cut, in an east and west direc-

tion, across the strike of easterly dipping Carboniferous, Triassic, Jurassic, and Cretaceous beds. That of Castle creek has a north and south course, and follows closely the line of a great fault and reversed fold, which brings Cambrian, Silurian, and Carboniferous beds up into juxtaposition with the red sandstones of the Trias. The reversed fold structure is well seen in a little hill on the east side of the Roaring Fork valley at the mouth of Castle creek, where the Jura-Trias beds rest upon the Dakota Cretaceous, as shown in Fig. 24, copied from Holmes. [62]

Immediately beyond Castle creek, in the angle between it and the Roaring Fork, lies Aspen mountain, a steep sharp ridge rising 2,000 feet (610 m.) above the valley, made up of faulted Archean, Cambrian, Silurian, and Carboniferous rocks.

The pretty mining town of **Aspen**, the second in importance in the State, lies in the valley of Roaring Fork at the east base of Aspen mountain. It is built upon a flood plain of the valley where it emerges from the Archean rocks of the Sawatch into the upturned Paleozoic beds which rest upon their flanks. These beds strike diagonally across

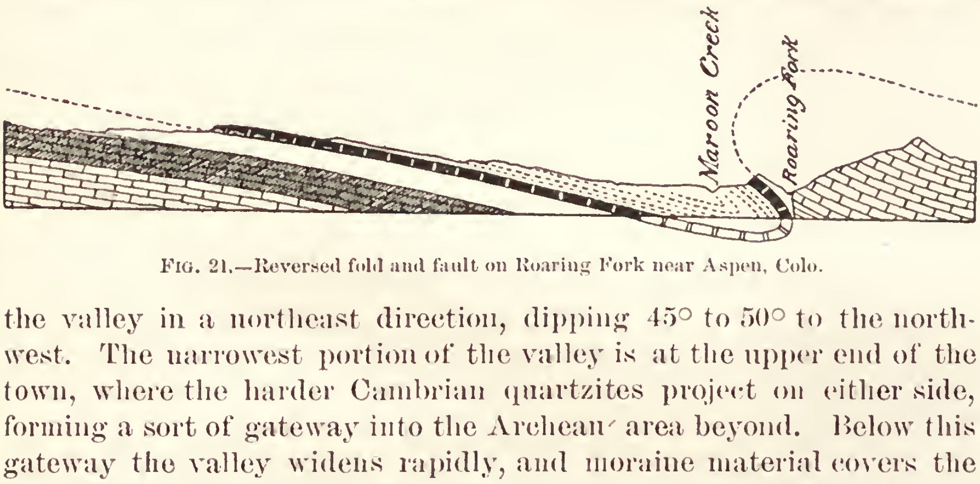


FIG. 24.—Reversed fold and fault on Roaring Fork near Aspen, Colo.

the valley in a northeast direction, dipping 45° to 50° to the northwest. The narrowest portion of the valley is at the upper end of the town, where the harder Cambrian quartzites project on either side, forming a sort of gateway into the Archean area beyond. Below this gateway the valley widens rapidly, and moraine material covers the lower slopes of the hills to an elevation of 1,000 feet, forming a broad bench on the east side of the valley.

The ores are sulphides, arsenides, and antimonides of silver, and sulphides of lead and iron, with their decomposition products. Barite is a common gangue material. They occur as a replacement of the Paleozoic limestones, the greater part being found in those of the Lower Carboniferous horizon, which are in great measure dolomitized in the vicinity of the ore bodies. Immediately above this limestone occurs a considerable thickness of black shales, in which is an intrusive sheet of diorite, generally decomposed.

The complicated geological structure of the region is the result of extreme compression of sedimentary beds against an unyielding Archean mass, which has thrust the beds into monoclinal and reversed folds,

and broken them by thrust faults. Along the upper ridge of Aspen mountain, to the southwest of the town, the rocks strike north and south and are broken into blocks by a series of north and south faults. Along Spar gulch, in which rich ore was first discovered, the strata bend in strike to the northeast, and continue in this direction across the valley into and beyond Smuggler mountain, which is the spur between the valley of Roaring Fork and that of Hunters creek. This portion is also broken by thrust faults, which run so nearly parallel with the stratification of the steeply dipping beds that they are difficult to trace.

The principal mines are in Aspen and Smuggler mountains, overlooking the town on either side, but rich developments are found for many miles along the horizon of the Lower Carboniferous, both north and south, always within a few hundred feet of the underlying Archean. The production of the region has been from $6,000,000 to $8,000,000 per annum for some years, but is now (1891) increasing. The Mollie Gibson mine on Smuggler Mountain has a most remarkable body of nearly pure polybasite, from which dividends are being paid at the rate of $100,000 per month.

GLENWOOD SPRINGS TO LEADVILLE.

ITINERARY.

By S. F. Emmons.

Station.	Distance.		Elevation.		Station.	Distance.		Elevation.	
	Miles.	Kilometers.	Feet.	Meters.		Miles.	Kilometers.	Feet.	Meters.
Glenwood	......	....	5,767	1,758	Avon	54	87	....	....
Shoshone	10	16	6,104	1,860	Minturn	60	97	7,809	2,380
Dotsero	18	29	6,139	1,871	Rock Creek	65	105	8,289	2,527
Gypsum	25	41	6,310	1,923	Red Cliff	67	108	8,656	2,638
Rio Aquila	32	52	....	....	Pando	74	119	9,227	2,812
Sherwood	40	64	6,886	2,099	Tennessee Pass	83	134	10,418	3,175
Wolcott	43	69	....	....	Keeldar	88	142	9,955	3,034
Allenton	47	76	7,129	2,173	Leadville*	90	145	10,185	3,104

*Population 11,212.

From **Glenwood** for 12 miles the road follows a narrow canyon cut by the Grand river in the Lower Paleozoic and Archean rocks at the southern base of the White River plateau. This canyon, which is bounded by vertical cliffs weathered into picturesque castellated forms, reaches a depth of 3,500 feet, the White River plateau immediately north of it being 5,000 feet above the river bed.

After leaving **Glenwood** the strata gradually rise, and beyond the tunnels the Archean rocks are suddenly brought up, apparently by a fault. They consist of red and gray granites, inclosing masses of gray gneiss and dark amphibolite, and traversed by irregular veins of pegmatite. These rise, midway in the canyon, 500 to 1,000 feet above the river bed, and gradually descend to the eastward. Their unconformable contact with the overlying Paleozoic rocks can be distinctly traced for a long distance on either side of the river. At the east end of the canyon the harder Lower Paleozoic rocks (Cambrian, Silurian, and Lower Carboniferous) gradually sink below the river level, and the valley widens out in the overlying gypsiferous beds.

At **Dotsero** the road leaves the valley of the Grand, which bends to the north, to follow that of its main tributary, Eagle river,[63] which comes in from the east. Above the junction the hills on either side are capped by Triassic beds, forming the southeast fringe of the White River plateau. On the summit of those to the north is a basalt vent of extremely recent age, whose lava has run down the southwest face of the cliff and flowed for a considerable distance along the valley bottom, crowding the stream to its southern edge. The track passes for a half mile close to this remarkable coulée, and the singularly rough, ropy, and scoriaceous nature of its surface can be readily seen from the train. The absence of any evidence of erosion, and its relation to the river gravels unite to prove it the most recent known lava flow in Colorado.[64]

Before reaching **Gypsum** station the road enters the considerable east and west valley of the same name, so called from the abundant beds of gypsum in the soft shales and limestones of Carboniferous age, out of which it has been eroded. It is about 15 miles (24 km.) in length and occupies a gentle anticline in the contorted and folded gypsiferous beds, which form part of a general synclinorium included between the Park and Sawatch ranges on the east, and the White River plateau and Elk mountains on the west. These beds are peculiar to this region, the same horizon in other parts of Colorado being represented mainly by coarse grits with a very subordinate development of shales and limestones.

The valley has at one time been occupied by a fresh-water lake, presumably of Pliocene age, in which were deposited a series of soft pink marls, remnants of which can be seen on the north side of the river. Still more recent deposits of waterworn gravels, probably brought down by the floods which occurred at the close of the Glacial period, are exposed in the railroad cuts.

At the eastern end of the valley the gypsiferous beds sink down below the valley level and give place to sharply upturned Red Beds (Trias). The valley now bends to the northeast, and then takes a sharp

turn to the southeast in Elbow canyon, crossing the upturned Red Beds and entering a narrow syncline in Cretaceous rocks. In this syncline the Dakota sandstones are strongly developed and contain some coal seams. They are overlaid by the black shales of the Middle Cretaceous; the uppermost hard bed seen in the axis of the syncline is probably the Niobrara limestone, which is always a well marked horizon.[63]

The southeast course is maintained until the Red Beds appear again from under the syncline, when the road takes a more easterly course for about 10 miles (16 km.) across an area of rounded hills formed of Upper and Middle Carboniferous beds, already showing a larger proportion of grits in the vicinity of the ancient shore line of the Sawatch upheaval.

The road then enters Eagle River canyon, which it follows in a southeast course for over 15 miles (24 km.). This picturesque gorge is cut along the north and northeast flanks of the Archean uplift of the Sawatch. Its bottom, which is from 1,000 to 1,500 feet (305 to 457 m.) below the level of the surrounding country, is generally in the underlying granite and gneiss, the summits of the cliffs being formed of Cambrian quartzites, and Silurian and Lower Carboniferous limestones, which dip 10° to 15° to the northeast, succeeded in the higher hills to the north by several thousand feet of grits and sandstones of Middle and Upper Carboniferous age. The aggregate thickness of the Lower Paleozoic series, up to and including the Lower Carboniferous, is only about 600 feet (183 m.), of which about 300 feet (91 m.) are quartzites.

Shortly after entering the canyon, shaft houses of various mines are seen perched high up on the cliffs to the north of the road, from which long aerial wire tramways for the transportation of ore reach down to the level of the railroad. These are a portion of the mines of Battle mountain in the Red Cliff mining district, whose ores are shipped from **Rock Creek** and **Red Cliff** stations to various smelting works throughout the country.

Red Cliff Mining District.—The ores of this district are found at two distinct horizons, without any visible connection between them.

The first are bodies of iron pyrite with argentiferous galena, in the Lower Carboniferous or Blue dolomitic limestone, beneath an intrusive sheet of quartz-porphyry. They occur in immense bodies as a replacement of the limestone, but are generally of rather low grade. The manner of successive alteration of such ores by surface or oxidizing waters through sulphates to oxides can be remarkably well seen in some of the mines.[65]

The second horizon is 200 to 300 feet (61 to 91 m.) lower geologically, at the top of the white Cambrian quartzite. The ores are in smaller volume and more irregular in distribution, but very much richer. They

are fine-grained ochreous material, consisting largely of basic sulphate of iron, containing silver and gold, which is in general not visible to the naked eye, though many fine nuggets of gold have been found. There is good ground for assuming that these metals have, in part at least, been leached from the ore bodies of the higher horizons in solutions of persulphate of iron.[66]

The mines are mostly situated near the mining town of Clinton or Battle mountain, on a shoulder of the cliffs about two miles north of **Red Cliff** station.

Near **Red Cliff** the Cambrian quartzites, which have come down to the valley level, are stained by iron oxides to a pinkish color. The narrow gorge continues for some miles beyond **Red Cliff**, and the valley then widens. In the more open valley two curved ridges can be distinguished, which are terminal moraines marking halts in the retreat of a glacier which once stretched down from the base of the Mosquito range, 15 miles (24 km.) to the eastward.

The railroad ascends gradually along the southeast wall of this valley, from which good exposures of the Paleozoic series up to the Upper Carboniferous, with sheets of intrusive porphyry, can be seen on the opposite side.

It then bends southward up a side valley in Archean gneiss to **Tennessee pass** (10,400 feet—3,170 m.) which forms part of the Continental divide separating the waters of the Pacific Ocean from those flowing into the Gulf of Mexico.

It passes the summit of the pass through a long tunnel, beneath a thin sheet of Cambrian quartzite which forms the summit of the pass, and descends on the other side, past exposures of Cambrian quartzite and Silurian limestone on the east, into the broad Pleistocene valley, known as Tennessee Park, at the head of the valley of the Arkansas. At the lower end of this park it bends to the eastward across the East fork of the Arkansas, up whose glacial-carved gorge may be distinguished some of the high peaks of the Mosquito range in which it takes its rise. It then rises over a gently sloping mesa formed of glacial lake beds to the city of Leadville, which is situated on the edge of the mesa, at the base of the western spurs of the Mosquito range.

LEADVILLE.[67]

By S. F. Emmons.

This is the most important mining district in Colorado, and since the falling-off in the production of the Comstock, has been the greatest silver-producer in the whole West. Like so many other silver districts, it owes its existence to the restless wanderings of the early pioneers in search of gold. Gold was discovered in the neighboring gulches in 1860; the richest portions of the placers were exhausted in a few years, and the settlements that had sprung up around them were practically abandoned. When, fifteen years later, it became generally known that the heavy iron-stained stones, which had so much annoyed the gold washers, were rich silver ores, a new excitement, or "boom," among miners resulted; and, where in 1878 a few scattered log houses were all that were to be seen of human occupancy, in 1880 already a city of nearly 15,000 inhabitants had sprung up, with smelting works, banks, theaters, and all the adjuncts of a prosperous mining center. The town of to-day, though more substantially built, and with a population which, though somewhat less numerous, has also a smaller proportion of restless prospectors and adventurers and more substantial business men, still shows many characteristics of that which first sprung into existence with such marvellous rapidity.

The value of Leadville's product, in the thirteen years since it became a silver camp, has been between one hundred and fifty and one hundred and sixty millions of dollars. The annual product now varies from ten to fifteen million dollars, the principal value of the ores being in silver and lead, with a small proportion of gold.

The city is situated at the western base of the Mosquito range, on the upper edge of a gently-sloping mesa, about four miles east of and 600 feet above the bottom of the Arkansas valley. This mesa is formed of rudely-stratified beds of coarse gravel and sand, washed down from the adjoining mountains at the close of the first glacial period and deposited in a lake which, at that time, filled the Upper Arkansas valley above the present canyon at Granite. The moraines left by the glaciers of the second glacial period extended out over these beds, and their rearranged material, locally known as "wash," an unstratified drift, covers the lower portions of the hills and the intermediate valley. The depth of these successive gravel deposits immediately under Leadville is 300 to 400 feet and upwards.

From the city a fine view is had of the Arkansas valley and of the Sawatch mountains beyond it. That of the Mosquito range is much less satisfactory, owing to foreshortening. To the east of the city the ground slopes upward in a succession of benches or gently-rounded hills, known successively as Fryer Hill and Carbonate Hill, Yankee Hill and Iron Hill, etc., in which, as will be readily perceived from the unsightly dumps of waste that disfigure their surfaces, mining has been most extensively carried on. Although the greatest amount of underground work has been done within a mile or two of the town, within which distance there is an almost continuous network of subterranean passages reaching down several hundred feet from the surface, rich mines are by no means confined to this area, but are found up to the very crest of the range, at altitudes of 12,000 to 13,000 feet, and also beyond the crest on its eastern slopes.

The various smelting works, in which a portion of the ores produced here are smelted, are situated along the streams issuing from the mountains at either extremity of the city.

The greater part of the ores come from ore bodies in the Lower Carboniferous limestone, generally known as the Blue or ore-bearing limestone. During the first few years the productive minerals were carbonates of lead, and chlorides and bromides of silver, in a gangue of iron and manganese oxides mixed with clay and silica. These ochreous-looking ores are generally known among miners as "Carbonates," irrespective of whether the lead occurs, as here, mainly in the form of carbonate, or, as at Red Cliff in similar deposits, largely as sulphate. All these ores, being the result of secondary alteration by surface waters —a natural process of concentration that has removed a larger proportion of worthless materials, such as sulphur and zinc, than of the precious metals—were not only richer but better adapted for smelting than those which are obtained at the present day from the unaltered ore bodies below the zone of oxidation. While, therefore, the aggregate annual product of the district in tons of ore has regularly increased, its intrinsic value has fallen somewhat below that of early days.

As at present mined, the ore bodies, which are of enormous size, consist mainly of galena, iron pyrite, and zinc blende. Copper has, as a rule, been conspicuously absent, but of late years a deep-seated ore body, at a lower geological horizon than those generally worked, has been found to carry a considerable proportion of its value in this metal in an admixture of copper pyrite. In some of the large pyrite bodies small but appreciable quantities of tellurium occur. In others, bismuth has been found with the lead carbonates, and these also carry an unusually large proportion of free gold. Gold is found generally in deposits occurring exclusively in the porphyry bodies and quartzites; in them it is not infrequently associated with galena. The limestone

ores, except in certain limited areas, do not contain an appreciable amount of this metal.

The geological structure of this district is extremely complicated. Its principal mines are situated on one of the western spurs of the Mosquito range, which range, as has already been explained, is a portion of the Sawatch massive, uplifted into its present position by faulting. This faulting was not, however, a simple uplifting of the strata without plication or compression, as has been described as the characteristic structure of the Plateau region. It was, on the contrary, primarily a plication produced by powerful compression against the unyielding Archean massive (Horst, Butoir) of the Sawatch. Faulting has been the final result, where the limit of plasticity of the involved rock masses had been reached. The relative plasticity of different portions of these rock masses appears to have borne an inverse relation to the amount of intrusive beds and laccolitic masses, which already formed an integral part of the sedimentary beds involved before the inception of the plication. Where these were only in thin sheets, as on the eastern flanks of this range, sharp anticlinal folds, generally much steeper on the western side, were formed before actual fracturing and displacement took place. The faulting in such cases occurred on the steeper side of the fold, where the tension was greatest. With a relatively greater proportion of eruptive rocks to sedimentary strata, plication was less marked and faulting more frequent. In the immediate vicinity of Leadville, where the eruptive sheets greatly exceed in volume the sedimentary beds above the Archean, with which they are practically interstratified, faulting has been a much larger factor in the uplift than plication, and the spur in which the principal ore deposits occur consists of a number of blocks, each faulted up to the eastward above the other, and traceable in the present topography as shoulders or hills. These faulted blocks are not, however, as might appear at a first glance, simple uplifted monoclinals, but form part of a system of synclines and anticlines, whose axes bear a definite, though sometimes rather obscure, relation to the planes of the various faults.

The prominent phases in the geological history of the region, as far as they have yet been deciphered, are—

1. Successive intrusions of porphyry, the earliest of which (White porphyry) was generally parallel to the stratification, spreading out in places into laccolitic bodies. The later intrusions (Gray porphyry) were more frequently tranverse to the bedding, and formed thinner and more dike-like bodies, probably following to some extent planes of fracture produced by the shattering attendant upon the earlier intrusions.

2. During the second phase occurred the orignal ore deposition, which was a concentration of the metals disseminated through the rock

masses along channels formed during the preceding phase—contact planes between eruptive and sedimentary rock masses, and planes of fracture traversing either. The deposition of ore took place mainly in the Blue or Carboniferous limestone, and was a process of replacement of this rock by metallic minerals in the neighborhood of these channels, the original rock structure being in many cases preserved in the ore body.

3. The third phase was produced by the dynamic movements which resulted in folding, faulting, and displacement both of the sedimentary and eruptive rocks, and of their included ore bodies.

4. The final phase has been the gradual wearing away and degradation of the uplifted masses and the carving out of the present mountain forms, so that the ore bodies, formerly deeply buried, have been brought near the surface and exposed to the action of atmospheric waters. These reached them readily along the great fault lines and down the gently dipping stratification planes, and changed not only their mineralogical and chemical composition, but to a certain extent their position. The great accumulations of gravels, which cover all the lower portions of the hills and valleys, have probably rendered especially active the decomposing action of surface waters, as they contain a sufficient admixture of clay to render them capable of holding within their mass a great deal of water, after the manner of a sponge, and thus giving it time to act more thoroughly and deeply than if it were rapidly and freely drained away.

LEADVILLE TO MANITOU.

ITINERARY.

Station.	Distance.		Elevation.		Station.	Distance.		Elevation.	
	Miles.	Kilometers.	Feet.	Meters.		Miles.	Kilometers.	Feet.	Meters.
Leadville*	0	0	10,185	3,104	Vallie	78	126	6,534	1,992
Malta	4	6	9,565	2,915	Cotopaxi	84	134	6,371	1,942
Crystal Lake	7	11	9,317	2,840	Texas Creek	91	146	6,203	1,891
Hayden	12	19	9,143	2,787	Parkdale	106	171	5,722	1,744
Twin Lakes	16	26	9,012	2,747	Canyon City	116	187	5,329	1,624
Granite	18	29	8,930	2,722	Florence	124	200	5,184	1,580
Pine Creek	22	35	8,640	2,633	Beaver	134	216	4,983	1,519
Riverside	27	43	8,357	2,547	Carlile	137	220	4,936	1,504
Americus	31	50	8,125	2,476	Swallows	142	228	4,863	1,481
Buena Vista	35	56	7,955	2,425	Meadows	147	237	4,797	1,461
Midway	38	61	7,837	2,388	Goodnight	153	246	4,713	1,436
Nathrop	43	69	7,680	2,341	Pueblo	157	253	4,653	1,418
Hecla Junction	51	82	7,356	2,242	Eden	165	266	....	....
Browns Canyon	53	85	7,307	2,227	Buttes	183	294	5,355	1,632
Salida	60	97	7,034	2,144	Fountain	188	303	5,552	1,692
Cleora	62	100	7,000	2,134	Colorado Springs	202	325	5,978	1,822
Swissvale (Badger)	68	109	6,852	2,088	Manitou	207	333	6,309	1,923
Howard	72	116	6,699	2,042					

* Population, 11.212.

[By S. F. Emmons.]

From **Leadville** the road descends over the gently sloping mesa of Pleistocene lake beds to the Arkansas valley bottom at **Malta.** It then follows the level river bottom southward for 12 miles and enters a narrow, winding gorge in Archean granite. The old outlet of the lake that once filled the upper portion of the Arkansas valley lies to the west of the present course of the stream, nearer the base of the Sawatch mountains. It is now filled with gravels and crossed by magnificent moraine ridges of the later glacial epoch. These gravels carry gold, and it was this that attracted the first miners to this region in 1860. A flume carrying water for hydraulic washing crosses the railroad on the right. As one descends the valley, many abandoned placer washings in the coarse glacial gravels can be seen.

Twin Lakes is the station from which the beautiful glacial lakes a few miles to the westward are reached. These lakes lie at the opening of a magnificent gorge in the Sawatch range and are formed by terminal moraines, a moraine ridge separating the one from the other.[68]

Granite was the first town founded in this region, in 1860, by the gold-placer miners. Above it on the east are the abrupt granite slopes of the Mosquito range, cut through by frequent dikes of porphyry. The road follows a narrow gorge cut by the stream on the east side of the valley and then enters a broad, open valley of gently sloping Pleistocene gravels, which it follows for over 30 miles.

From **Buena Vista** fine views are had of the high peaks of the Sawatch range to the west. Mount Harvard (14,375 feet—4,381 m.), is an enormous mass; next to it, Mount Yale (14,187 feet—4,324 m.); to the south of west rise Mount Princeton (14,246 feet—4,342 m.), Mount Antero (14,246 feet) and Mount Shavano (14,239 feet—4,340 m.). On the slopes of the Mosquito range, east of the town, can be distinguished the line of the Colorado Midland road, which passes up the valley of Trout creek and crosses the Mosquito range into the South Park. Between **Midway** and **Nathrop** the road passes for a short distance through a narrow gorge cut in the granite, on the east side of the valley.

[By WHITMAN CROSS.]

At **Nathrop** are several rhyolite masses forming oblong hills with trend north-northwest to south-southeast. That these masses are huge dikes is shown by steeply inclined contacts with gneiss, parallel to which the eruptive rock is banded, the outer zone being glassy. The rhyolite of Ruby hill, on the eastern bank of the Arkansas directly opposite the station, is a lilac-colored banded rock with lithophysal cavities arranged on certain planes, containing many beautiful crystals of manganese garnet (spessartite) and topaz. [69] Good specimens can easily be obtained, and many have been collected by mineral dealers. On the west side of the river, near the railroad and north of the station, a small ridge of rhyolite rises out of the valley bottom, which is made of a rock containing phenocrysts of smoky quartz and feldspar and small lithophysæ containing minute topaz and garnet crystals.

At **Browns canyon** the road traverses another gorge on the east of the valley cut in Archean rocks, mainly coarse granite and amphibolite.

At **Salida** a considerable stream, known as the South Arkansas, joins the main river from the west. The original western line of the Denver and Rio Grande railroad follows up the valley of the South Arkansas, crossing the southern end of the Sawatch range at Marshall pass (10,481 feet—3,304 m.), and descending along the valley of the Gunnison to **Grand Junction.**

At **Poncho**, four miles west, are thermal springs. On the western side of the valley, from here northward to **Buena Vista**, are gently sloping

mesa-topped ridges, covered by Pleistocene beds and underlaid by upturned beds of earlier Tertiary, whose age has not yet been determined. The view of the Sawatch Mountain peaks to the northwest and Mount Ouray on the west is here very fine.

The hills on the eastern side of the Arkansas, for several miles above and below **Salida**, are mainly composed of a series of crystalline schists and some more massive bands, which have been referred to the Algonkian period.* The known exposures of this series of rocks extend from a point about four miles (6 km.) north of **Salida** southward along the eastern bank of the river to where it bends east into the sedimentaries, which cover them, and thence westward into the north end of the Sangre de Cristo range. Immediately opposite **Salida** andesitic breccia conceals the schists for nearly one mile (1.61 km.) back from the river, and at six miles (10 km.) or more the sedimentary rocks in remnants are found on the edges of the schists. Their outcrops to the north are limited by andesitic breccia.

As now known, these schists are derived from eruptive rocks of at least two kinds, one acidic and one basic, which originally succeeded each other in a long series of alternating flows, probably with tuffs or fragmental deposits of the same materials in certain places. The most massive rocks now preserved are those occurring in the Arkansas valley below **Salida**, and the most altered schistose forms are at the northern extremity of the known section. Here are fine schistose rocks variously characterized by mica, chlorite, garnet, staurolite, and various amphiboles. One loose-fibered actinolite schist is locally so impregnated by copper ores that the material has been mined at a profit. The principal mine, the "Sedalia," is situated on the hillside facing the Arkansas valley, about three miles (5 km.) north of **Salida**. In a chlorite schist adjoining the copper-bearing layer occur the huge dodecahedral garnets which have been so widely distributed over the world through mineral dealers.

[By S. F. Emmons.]

Below **Salida** the Arkansas valley changes from a southern to an eastern course, across the southern extension of the Mosquito or Park range to the Colorado or Front range.

At **Cleora** the valley narrows and the road passes over the more massive rocks of the schistose series into Lower Paleozoic beds, dipping to

*In the month following the excursion of the Congress the writer was able to examine, in some detail, the schistose series in question, and the statements as to its character here given are based on this recent study. The strata visited by some of the geologists in the ravine east of Salida belong to the most thoroughly metamorphosed part of the series, and their origin is clear only through the intermediate stages found in other parts of the section.

the northeast. The Cambrian quartzite is not distinctly recognized. The Silurian is represented by grayish limestones, the Lower Carboniferous by dark blue or gray limestones. Above these come a series of black shales and impure limestones, belonging to the Middle Carboniferous, followed by a great thickness of purplish-red beds, sandstones, conglomerates, and shales, which constitute the Middle and Upper Carboniferous, a horizon whose lithological constitution varies much in the Rocky Mountain region. As yet only plant remains have been obtained from these beds. Their apparent thickness is magnified by a secondary roll, and probably by some faults. Still above them are the finer-grained, bright-red sandstones which here constitute the Red Beds of probable Triassic age.

At **Badger** station the valley widens, and rocks in the immediate vicinity of the road are obscured by Pleistocene gravels.

From **Howard** station a fine view is obtained, through the hills to the southwest, of the peaks of the Sangre de Cristo range, which forms the southern continuation of the Sawatch and Mosquito uplifts, though not in a direct line with either.

Beyond **Vallie** station the road leaves the open valley and passes into a gorge of Archean, on the west flanks of which rest thin-bedded limestones dipping westward. The Archean rocks consist mainly of dark gneisses and amphibolites, with intrusive red granite, showing considerable regularity of structure.

From **Cotopaxi** station a stage line runs south into the Wet Mountain valley, a great interior depression to the southward between the Sangre de Cristo range on the west and the Wet mountains (which face the Great Plains) on the east, in which is the Silver Cliff mining district.[70]

The road now passes for several miles through a peculiarly crumbling, massive red granite, which is found in most of the deep cuts across the Archean mass of the Rocky Mountains, and is apparently a lower portion of the Archean series.

Texas Creek, the next station, is at the mouth of a stream of that name which drains the northwestern portion of the Wet Mountain valley. The Arkansas valley here opens out in the crumbling red granite, but narrows again a few miles to the eastward, passing into granite-gneiss, with an apparent bedded structure dipping to the eastward. It contains large pegmatite veins and a considerable development of amphibolite schists. The road then passes into another small open valley above **Echo** station, from which, looking up the northern tributary valleys, can be distinguished hills capped by dark lavas.

Beyond **Echo** the road passes again into a winding gorge of granite-gneiss, whose structure lines dip 50° to the east. Through this are intrusive masses of coarse grey granite and pegmatite veins.

At Parkdale is a considerable open valley, in which are nearly horizontal Cretaceous beds lying unconformably upon Silurian limestones. These were deposited in an ancient bay, which connected with the ocean to the eastward, both to the north and south of the Archean mass through which the railroad now passes.

For nearly 10 miles the road now follows a deep canyon, known as the Royal Gorge, whose walls rise almost perpendicularly above the track two or three thousand feet. This is probably the most imposing canyon gorge that is traversed by railroads in Colorado. The rocks are largely dark gneiss and amphibolite, cut by eruptive granite, pegmatite veins, and narrow diabase dikes, and show distinct structure lines which stand almost perpendicular. Just as the river emerges from the canyon it is joined by Grape creek, a rapid stream which comes down another narrow, winding gorge from the northwest portion of Wet Mountain valley. Just east of the mouth of Grape creek, and on the south side of the river, is a low ridge of Silurian sandstones and limestones resting directly upon the Archean. At the northern end of this ridge are hot springs, where are bath houses and a hotel adjoining. The thermal waters issue from the Silurian limestones.

From the Archean gateway of the Royal Gorge the road passes for a mile across an interior monoclinal valley between the foothills and a hogback ridge, formed by the hard sandstones of the Dakota Cretaceous. This monoclinal valley stretches ten miles due north, parallel to the eastern slope of the mountains. It is bounded on the east by a very steep wall, formed by the edges of the Dakota sandstones, and slopes gently up to the west against the flanks of the Archean. These slopes are made up of Silurian and Lower Carboniferous sandstones and limestones resting uncomformably upon the Archean, and in turn uncomformably overlaid by limestone breccia and soft arkose sandstones, whose age has not yet been definitely determined, but is either Carboniferous or Trias. Out of the softer rocks the bottom of the valley has been eroded. Above them rest the Jura-Dakota sandstones, again unconformable, though where crossed by the railroad there is no marked discrepancy in the angle of dip. East of the Hogback ridge are quarries in Niobrara limestone, worked by convicts from the State penitentiary at Canyon City.

SILURIAN VERTEBRATE LIFE AT CANYON CITY.

[By C. D. Walcott.]

Canyon City is situated near the southwestern shore of a great bay of early Silurian (Ordovician) time, an arm of which reached inland as far as Parkdale. Along the western shore of this bay sediments were deposited that now form the sandstones and limestones of the monoclinal valley above mentioned.

The lower division of the Silurian consists of sandstones (86 feet). In these, 11 genera and 19 species of invertebrate fossils have been found and an immense number of fragmentary remains of ganoid fishes. The invertebrate fauna is of the type of the basal Trenton of the New York section. The icthyic fauna includes fragments of a Placoderm closely allied to *Asterolepis*, numerous scales of the character of those of *Holoptychius*, and what is considered to be the calcified chordal sheath of a form allied to the recent *Chimæra monstrosa*. This fauna was the subject of a paper read before the Geological Society of America at its recent session.[71]

The typical section is seen at Harding's quarry, which is about one mile northwest of the State penitentiary at Canyon City.

The invertebrate fauna, occurring three feet above the uppermost fish-bearing stratum, includes 34 genera and 55 species, of which 27 have been identified. At an horizon 180 feet higher in the section, 33 genera and 57 species occur, of which 33 species have been identified. These faunas are respectively of the types of those of the Lower and Upper Trenton faunas of the New York section, or the Lower and Upper Bala of Wales.

The character of the fauna at the lower horizon is shown by *Receptaculites Oweni*, *Halysites catenulatus* (a Lower Bala and Llandeilo species); *Columnaria alveolata; Strophomena alternata; Streptorhynchus filitextum; S. sulcatum; Orthis biforata; O. flabellum; O. subquadrata; O. tricenaria; Rhynchonella capax* var. *increbescens; R. dentata* Hall; *Ambonychia bellastriata*, Hall; *Modiolopsis plana*, Hall; *Murchisonia tricarinata*, Hall; *Cyclonema bilex; Bellerophon bilobatus*, Sow; *Endoceras proteiforme*, Hall; *Ormoceras tenuifilum; O. crebriseptum; Orthoceras vertebrale*, Hall; *O. multicameratum*, Hall; *Gomphoceras powersi*, James; *Asaphus*, like *A. platycephalus; Illænus crassicauda; I. milleri*. Of these, 11 species pass up into the fauna 180 feet above.

Six miles north of Canyon City limestones are exposed beneath the

MAP OF THE FLORENCE OIL FIELD, COLORADO.

Harding sandstone that in the section near **Canyon City** are concealed by the overlap of the Harding sandstone. The section is as follows:

	Feet.
5. Fremont limestone (estimate)	80
4. Halysites limestone (estimate)	100
3. Harding sandstone	145
2. Calciferous reddish limestone	4
1. Cherty, reddish Cambrian limestone	28

Characteristic Cambrian fossils were found in No. 1, and in No. 2 the genera *Ophileta* and *Bathyurus* occur.

The finest exposure of this series is found in Garden Park, north of **Canyon City**, where a plateau formed by the Halysites limestone is traversed by numerous canyons that cut down into the crystalline rocks beneath the Cambrian.

[By S. F. Emmons.]

In the beds immediately underlying the Dakota sandstones about 10 miles north of Canyon City abundant Saurian remains of upper Jurassic types (*Atlantosaurus*, *Stegosaurus*, etc.)[72] have been found.

From **Canyon City** the road passes out upon the Great Plains, whose surface from here to Pueblo is formed of the nearly horizontal clays and limestones of the Montana and Colorado Cretaceous. A short distance southeast of **Canyon City**, in comparatively close proximity to the foothills, a small synclinal basin of coal-bearing Laramie rocks has escaped erosion, and coal is actively mined. Just before reaching **Florence** the northern end of this basin is crossed, and the Laramie sandstones can be distinguished capping some high bluffs to the north of the river.

About **Florence** is an oil field whose product reaches 2,000 barrels per day. The oil comes mainly from the Pierre shales of the Montana Cretaceous, and is obtained from depths of 900 to 2,000 feet (275–610 m.). The accompanying map (Pl. IX), from a paper on the Florence oil field, by George H. Eldridge,[73] shows the geological structure of this region. It is on a scale of 3 miles to the inch, or about $\frac{1}{190000}$. The contours are at vertical intervals of 25 feet. The letters indicating geological subdivisions are: A = Archean; S = Silurian; C = Carboniferous; T = Trias; J = Jura; Kd = Dakota (Cretaceous); Kb = Benton; Kn = Niobrara; M = Montana; Kl = Laramie Cretaceous; q = Quaternary.

Beyond **Florence** the rocks rise slowly, and the road follows the river bottom a hundred feet or more below the level of the surrounding plains. In the bluffs which border this bottom can be distinguished the harder beds of Niobrara limestone, which rise and fall in gentle undulations along the route.

The city of **Pueblo** is important as a railroad center, and contains metallurgical works for reducing the various ores which are brought down grade from the mining districts of the mountains. On the mesa to the south, at Bessemer, are the iron and steel works of the Colorado Coal and Iron Company, where there is an extensive Bessemer plant for making rails. Nearer the town, on the mesa, are the lead-smelting works of the Colorado Smelting Company, managed by Mr. Anton Eilers, and to the north of the town and adjoining the railroad are the lead-smelting and refining works of the Pueblo Smelting and Refining Company, Herman Geist, manager. A permanent exposition building, known as the Colorado Mineral Palace, has recently been opened here for the purpose of exhibiting collections illustrative of the mineral resources of the State.

The road now bends northward up the valley of Fountain creek, about 12 miles (19 km.) to the east of the mountains, still remaining upon the clays of the Middle Cretaceous. As it gradually approaches the mountains, good views of the Pikes Peak group are obtained. The stream was originally named by Canadian trappers *Fontaine qui bouille*, from the effervescent springs near its source.

Colorado Springs is a flourishing city of 7,000 inhabitants situated upon the mesa, on the east bank of Monument creek, three miles from the mountains, whose mild, yet invigorating climate has made it famous as a health resort, especially for consumptives. The traveler has here a magnificent panorama spread out before him, the central feature of which is Pikes Peak, 12 miles (19 km.) away, towering above the lesser mountains and foothills. To the south is Cheyenne mountain (9,407 feet—2,867 m.), a precipitous peak rising abruptly from the plains, while to the west of it is St. Peters dome, a celebrated mineral locality. Between Cheyenne mountain and Pikes Peak is the picturesque gorge of Cheyenne canyon. A beautiful casino near by is connected by tramway with the city of **Colorado Springs**.

From **Colorado Springs** the train follows a branch road up the valley of the Fountain to **Manitou**, five miles to the westward, in a sheltered nook at the very base of the mountains.

Just beyond **Colorado City**, the first capital of Colorado, the upturned Niobrara Cretaceous limestone is seen, and from here the route crosses in succession the Lower Cretaceous, Jura, Trias, and Carboniferous, all steeply upturned. To the south of the track, the jagged edges of red Triassic sandstones are seen striking for the Archean foothills. A northwest-southeast fault cuts them off, as indicated on the Hayden map. To the north, the towering masses of the "Garden of the Gods" are seen from certain points.

MANITOU.

By Whitman Cross.

Manitou is a watering place and summer resort, celebrated for its springs of mineral water and the many objects of interest in its immediate vicinity. It has five large hotels and many smaller ones. The town lies in the valley of Fountain creek, in a little bay indenting the foothills of the Archean mountains. The sedimentary rocks occupying this bay are of Silurian and Lower Carboniferous ages, and do not appear elsewhere for many miles north or south. Although the details of the local geology have not been accurately worked out, the general structure is shown by the Hayden map.[74] To the north the strata are seen resting on Archean gneiss, with a southerly dip of 10° to 35° and running well up on the mountain slopes, but only small patches appear to the north of the stream which issues from the foothills at Glen Eyrie, three miles from Manitou. The disappearance of the formations in this direction seems to be caused by erosion preceding the Trias, for the shore line of the latter formation shows a transgression from the Archean obliquely across the Silurian and Carboniferous.

To the south of Fountain creek the Paleozoic, Triassic, Jurassic, and Dakota Cretaceous beds are successively cut off by a fault line with northwest-southeast trend. This line crosses Ruxton creek west of town, near the Midland Railroad bridge. In the line of this fault to the northwest is Manitou park, a long, isolated basin in the mountains, occupied by the Paleozoic formations seen at Manitou, but with a somewhat different development.

The best opportunity to see the Silurian beds and the contact with the underlying Archean is in Williams canyon, a narrow, picturesque gorge, whose mouth is close by the Cliff House. The canyon extends almost due north for about two miles, its nearly vertical walls, 300 to 500 feet in height, being mainly made up of Silurian limestone. Ascending the canyon from Manitou one descends geologically, owing to the southeasterly dip of the strata, and at about one mile from the town the contact of the thin quartzite under the limestone with the gneiss is very plainly seen. In the cliffs on the western side are extensive caves in the most massive stratum of limestone. The "Cave of the Winds" is open to visitors. There are several other caves at the same horizon in the vicinity of Manitou.

By passing up Ute creek to Rainbow falls, one mile from the bath house, another good view of the lower part of the Silurian section and

the Archean contact is obtainable. The line of the fault mentioned above is seen in going up Ruxton Creek to the Ute Iron Springs and to the depot of the Pikes Peak railroad.

The mineral springs, for which Manitou is famous, issue at several horizons in the sedimentary rocks and from the Archean. They are all carbonated and saline, while one of them is strongly chalybeate. The temperature of the water varies from 43° to 60° F. (6° to 15° C.). There is a bath house in connection with the larger soda springs. The Ute Iron Springs are in Ruxton valley.*

The "Garden of the Gods" is situated about one mile north of Fountain creek and three miles northeast of Manitou. In it rise towers and pinnacles consisting of the vertical strata of the white Dakota sandstone, or of the red Triassic sandstones below. Some of these huge masses rise vertically for 200 or 300 feet, and serve as fine examples of the erosion of steeply-upturned strata of varying consistency. Lower white ridges of Jurassic gypsum or of Cretaceous limestone afford strong contrasts in color when compared with the red sandstones.

Pikes Peak.—Pikes Peak rises to an elevation of 14,147 feet (4,312 m.), or 7,838 feet (2,389 m.) above Manitou. It is seven miles distant in air-line; is reached by cog-railroad, by horseback on path, or by carriage from Cascade station on the Colorado Midland railroad.

Pikes Peak is the center of a group of mountains which are mainly made up of a coarse reddish biotite granite. In the granite are many coarse pegmatite veins, and in some localities pockets lined by crystals of smoky quartz, amazon stone, and a large number of less abundant minerals. While these mineral occurrences have made the name of

*The following analyses of the waters of the principal springs are taken from Dr. A. C. Peale's Mineral Springs of the United States: [75]

MANITOU SPRINGS.

[Parts in 100,000.]

Constituents.	Oscar Loew, analyst.					
	Iron Ute.	Little Chief.	Manitou.	Navajo.	Ute Soda.	Shoshone.
Sodium carbonate	59·34	15·16	52·26	124·69	23·82	88·80
Calcium carbonate	59·04	75·20	111·00	129·40	40·00	108·50 (calcium and magnesium carbonate together)
Magnesium carbonate	14·56	13·01	20·51	31·66	6·10	
Lithium carbonate	Trace.	Trace.	0·21	0·24	Trace.	Trace.
Iron carbonate	5·78	1·80	Trace.	....	1·40	....
Sodium sulphate	30·86	51·88	19·71	18·42	12·24	37·08
Potassium sulphate	7·01	6·24	13·35	16·21	Trace.	5·12
Sodium chloride	31·59	47·97	40·95	39·78	13·93	42·12
Silica	2·69	2·22	2·01	1·47	Trace.	Trace.
Total	210·87	213·48	260·00	361·87	97·49	281·62

Pikes Peak known the world over, the mountain proper has yielded but few specimens of note. The chief interest in ascending Pikes Peak centers in the magnificent view of mountain and of plain to be obtained from its summit and from the cars in making the ascent. A beautiful alpine flora may be found below the débris of the summit, and especially on the southern slope.

FIG. 25.—Pikes Peak railway.

The above sketch by M. Eysséric, of the visiting geologists, was taken on the southern slope above timberline.

The list of minerals found in the granite of the Pike's Peak region embraces orthoclase, microcline, albite, biotite, muscovite, quartz (smoky

and clear), topaz, phenacite, kaolinite, arfvedsonite, astrophyllite, hematite, limonite (pseudomorph after siderite), goethite, turgite, cassiterite, rutile, zircon, fluorite, cryolite, pachnolite, thomsenolite, gearksutite, ralstonite, prosopite, elpasolite, tysonite, bastnäsite, allanite, xenotime, gadolinite, samarskite.[76]

A large number of minerals, including all the fluorides, zircon, astrophyllite, and arfvedsonite, occur near St. Peters dome, 10 miles (16 km.) southeast of Pikes Peak. This locality is reached by carriage from Colorado Springs, a full day being necessary for the trip. The same road leads to the Seven lakes at the south base of Pikes Peak, and along its course fine mountain views are obtained at many places.

Other points at which fine specimens have been found are scattered all over the foothills of Pikes Peak, but only at St. Peters dome will the casual visitor be likely to find valuable specimens himself. A fine collection of minerals for sale can be found at the Iron Spring in Ruxton creek, below the depot of the Pikes Peak railroad.

The locality which has furnishd the finest amazonstone crystals, and also phenacite and topaz, is near Florissant, a station on the Colorado Midland railroad, 30 miles (48 km.) from Manitou and 15 miles (24 km.) northwest of Pikes Peak. Fine topaz crystals have also been obtained at Devils Head (Platte mountain), 30 miles to the northwest.

In the vicinity of the village of Florissant is the small isolated lake basin of Upper Eocene (Oligocene) beds, which have become celebrated for their wonderful insect fauna and fossil flora. Fishes and, more rarely, birds have also been found here. The strata of this deposit are composed of volcanic ashes, and they can not as yet be accurately correlated with any beds known elsewhere. The geology of the basin has been described by S. H. Scudder.[77]

COLORADO SPRINGS TO DENVER.

ITINERARY.

By WHITMAN CROSS.

Station.	Distance.		Elevation.		Station.	Distance.		Elevation.	
	Miles.	Kilometres.	Feet.	Meters.		Miles.	Kilometers.	Feet.	Meters.
Colorado Springs ..	0	0	5,978	1,822	Larkspur	31	50	6,656	2,029
Edgerton	8	13	6,402	1,951	Castle Rock	40	64	6,205	1,891
Husted	13	21	6,582	2,006	Sedalia	49	79	5,822	1,775
Monument	19	31	6,960	2,121	Acequia	56	90	5,515	1,681
Palmer Lake	22	35	7,222	2,201	Littleton	63	101	5,357	1,632
Greenland	28	45	6,906	2,105	Denver	73	117	5,182	1,579

From **Colorado Springs** northward the route follows up the valley of Monument creek. For several miles its course is in Montana shales, but below **Edgerton** it enters the Laramie formation, which presents a line of bluffs facing to the southwest. Along the banks one sees from the train a tendency to the production of curious forms by the unequal erosion of the sandstone containing hard and usually ferruginous layers. In the district lying to the west of the railroad is the celebrated Monument park, where the erosional forms are most abundant and noteworthy in shape and size.

The road gradually approaches the Archean foothills, and at the head of Monument creek reaches the divide between the waters of the Arkansas and Platte rivers. This divide extends for many miles eastward with a general elevation of about 7,500 feet. It is timbered in certain areas and is composed of Tertiary strata, most of which are assigned to the Monument Creek formation of Hayden, though detailed studies may very probably show that several distinct formations have been grouped as one. Owing to a discovery of Miocene vertebrate remains somewhere in this series the whole has been supposed to be of that age.

The railroad crosses the divide at **Palmer Lake**, within a hundred yards of the Archean line, and just west of the station may be seen strata of the Monument Creek formation resting on granite, with a gentle easterly dip. East of the station is a small lake on the summit of the divide. It has been artificially enlarged. East of the lake rises a hill in which are good exposures of the coarse-grained grits and sandstones of the Monument Creek. On either side of the divide the usual zone of upturned sedimentary rocks, following the Archean contact, is

concealed by the Tertiary strata which abut against the foothills. On the northern side of the divide the road again diverges from the foothill line and passes rapidly down into the valley of Plum creek, which it follows to the Platte river. The most striking feature of the landscape, for a considerable distance, is the number of isolated flat-topped buttes, which are made up of Monument Creek strata with, in many cases, a capping of pinkish rhyolitic tuff, a rock much used as a building stone in **Denver.** These buttes are specially well shown in the vicinity of **Larkspur, Douglas,** and **Castle Rock.** The quarries from which the tuff is obtained are near the last two stations. In Castle Rock, a small hill with abrupt cliffs at the top, is evidence of an erosion which followed the tuff deposition, and indicates a division line in the Tertiary series, the importance of which has not yet been demonstrated. Tertiary beds extend somewhat farther north than is represented by the Hayden map, and it is not until within a short distance of the Platte river that the underlying beds are exposed.

Below **Sedalia** the line of upturned strata following the mountain base becomes again visible, and the Dakota hogback in particular can be traced for miles. Shortly before reaching **Acequia** a large irrigation ditch is crossed, by which water from the Platte is conducted to the dry plains immediately east of Denver. Opposite **Acequia** is seen the gap through which the Platte river issues from the mountains. From the mouth of Plum creek to **Denver** the route passes over the two post-Laramie formations—the Arapahoe and the Denver—which will be referred to in detail below.

DENVER.

By Whitman Cross.

In 1859 the first log house was built where Denver now stands. In 1870 the city had 4,730 inhabitants; in 1880, 35,628; in 1890, about 140,000. In its business blocks, theaters, school buildings, and private residences Denver stands on a par with many older Eastern cities of a larger population.

The city is built on slightly terraced plains, along either bank of the South Platte river, at about 10 miles from the mountains. From a favorable point the observer commands a magnificent view of the Front range of the Rocky Mountains, extending from the northern line of the State southward to Pikes Peak, a distance of 150 miles (240 km.). The most prominent peaks visible from Denver are, commencing at the north, Longs Peak (14,271 feet—4,350 m.); Grays Peak (14,341 feet—4,371 m.); Mount Evans (14,330 feet—4,368 m.), and Pikes Peak

(14,147 feet—4,312 m.). A notable feature of the landscape is Table mountain, a gently-sloping mesa at the base of the mountains, directly west of Denver, where a basalt sheet has protected the soft underlying strata from erosion. Behind the mesa is the city of Golden.

Denver is the commercial center of a very large territory. It is of special importance through its relations to the mining industry of the mountainous region to the westward, for it is the greatest ore market of the Rocky Mountains. From mining camps, not only in Colorado, but also in the surrounding States and Territories, ore is brought to Denver, sampled, and sold in the public market.

There are in the city three very large smelting establishments. Of these the Boston and Colorado Smelting Company, whose works are in the suburbs at Argo, deals principally with the more refractory ores, and pays especial attention to ores containing copper, silver, and gold. The process is a modification of the Ziervogel process. The gold is separated from the copper by an operation which is kept secret. The Omaha and Grant Smelting and Refining Company, whose refining works are at Omaha, is said to be the largest establishment of its kind in the world. Argentiferous lead ores, such as those of Leadville and Aspen, are the ones most sought for here, as also at the Globe Smelting Works, near Argo, where some of the largest lead furnaces in the world are in operation.

Among the public buildings worthy of note is the State capitol, now being erected on a beautiful site on Capitol hill; the Arapahoe County court-house on Sixteenth street, built of a grayish sandstone from the Laramie Cretaceous, and the High School building, one of the largest school edifices in the United States. In the upper corridors of the last-named building are temporarily displayed the collections of the Colorado Scientific Society, which are well worthy of a visit, especially for the mineralogists.

A mining-stock exchange, started a few years ago, is now erecting a handsome building for its use.

The visitor will, undoubtedly, note the great variety of beautiful building stones used in Denver. These are nearly all the product of the State, and many of them come from quarries near the city. From the Archean comes a coarse-grained red granite and a fine-grained gray granite. The red sandstones of the Trias and Jura are much used. White sandstones come from the Dakota Cretaceous, or much more commonly from the Fox Hills or Laramie Cretaceous. The latter rocks are very easily worked and have various soft tints of gray, brown, or yellow. Beautiful marbles of white and variegated colors occur in Colorado, but have not yet been used to any great extent. One of the most popular building stones, especially adapted for residences, but also used in the Union Depot and in other large buildings

is the light pinkish rhyolitic tuff intercalated in the Tertiary strata south of Denver. The fine flagstones used in the sidewalks of Denver come from the red beds of the Trias or from the Dakota Cretaceous.

The geological formation immediately underlying and surrounding the city is the Denver beds, [79] a fresh-water lake deposit whose sandstones and conglomerates are characteristically, and in the lower portion almost exclusively, made up of volcanic rocks, representing many varieties of andesite. The Monument Creek beds rest unconformably upon the Denver strata in the highlands to the southeast.

Below the Denver beds occurs another fresh-water lake deposit, the Arapahoe beds, whose most prominent member is a conglomerate free from volcanic materials, but containing pebbles of sedimentary rocks recognized as belonging to various horizons from the Laramie down to the red sandstones of the Trias. Below the Arapahoe beds come the normal Laramie Cretaceous clays and coal-bearing sandstones. Unconformities of deposition occur between the Laramie and Arapahoe, and between the latter and the Denver beds. [81]

Both the Arapahoe and the Denver beds contain numerous fragments of *Dinosaurian* remains, the majority belonging to the recently discovered family of the *Ceratopsidæ.* The fossil flora of the Denver beds is very rich, but paleobotanists have not as yet differentiated it from that of the coal-bearing Laramie of this region. The molluscan fauna is small, but also shows a close relationship between the Denver and the Laramie. For these reasons paleontologists have held that the two lake deposits in question belong to the Laramie Cretaceous, but the stratigrapher finds, in the evidence of enormous erosion preceding the Arapahoe epoch and of a long period of eruptive activity before the Denver epoch, grounds for holding that these formations should be distinguished from the Laramie proper, and that they are either of earliest Eocene age or of a Cretaceous period succeeding the Laramie.

The Denver strata are exposed in the banks of the Platte river, and in many of its smaller tributaries; but a good idea of the characteristics of the series can only be obtained by examining the sections shown on the line of folding near the mountains. The rusty brown sandstones appearing on the plains are often indurated by a large amount of zeolitic cement, and the soils resulting from the decomposition of the eruptive materials are quite fertile.

A few years ago artesian water of remarkable purity was struck in Denver while boring for coal. The water was found to come from several horizons between 175 feet and 1,200 feet in depth, mainly in the Arapahoe beds. As the supply basin was a small one the large number of wells which were sunk soon decreased the pressure, and to-day nearly all the wells in use are pumping wells.

The formations constituting the plains about Denver are chiefly a

Loess-like Pleistocene deposit, which forms a very rich soil, though from lack of moisture the plains appear to be arid, and until irrigated produce little beside the prickly-pear cactus (*Opuntia*), the soap weed (*Yucca*), the sagebrush (*Artemisia*), greasewood (*Sarcobates*), and scanty grasses. This Loess deposit is widely distributed over eastern Colorado, and seems to connect directly with that of the Missouri valley.[80]

From Denver a number of very interesting excursions can easily be made to points illustrating clearly various features of the foothill geology. At Platte canyon, Morrison, Golden, Ralston creek, Boulder, and St. Vrain's creek, all reached by railroad, one can study beautiful sections of the upturned sedimentary series from the Archean to the Colorado Cretaceous, or, in some cases, to the post-Laramie of the Denver formation. The excursions to Morrison, Golden, and Ralston creek are easily made from Denver in one day, returning to the city at night. There are good hotels both at Morrison and Golden.

EXCURSION TO MORRISON.

By Whitman Cross.

Morrison is a little village 12 miles (19 km.) southwest of Denver, at the end of a branch of the Denver, Leadville and Gunnison railroad. It is picturesquely situated on the banks of Bear creek, which here issues from the mountains, crosses the monoclinal valley between the Archean and the Dakota hogback, and cuts its way through the latter to the plains. Just within this gap is the town, with fine exposures of the Mesozoic section below the Colorado Cretaceous close at hand.*

Dark red Triassic sandstones at the base of the sedimentary series form the most prominent outcrops seen in the section on the north bank of Bear creek. Above them comes a creamy white sandstone, and above that, forming a low ridge at the base of the Dakota hogback, is a limestone which is burnt for quicklime. This limestone occurs in the midst of red clays and shales. Mr. Eldridge has included these beds in the Triassic part of the section, differing in this from the division adopted by the Hayden survey.

The smooth western slope of the great Dakota hogback exhibits very beautifully the variegated marls, clays, and shales of the Jura. At a

*Fig. 26, on page 439, is a reproduction on half scale of the drawing by W. H. Holmes, published in the Hayden report for 1874, p. 32. The section given is on the north bank of Bear creek and shows the relationships of the various formations which can be easily visited, from the Archean gneisses of Bear canyon or Mount Morrison on the west, through the sedimentary section beginning with the red beds of the Trias, and extending to the highest known Denver beds in the summit of Green mountain on the east.

horizon not far below the Dakota, and on the slope facing the town of Morrison, Prof. Arthur Lakes found the first gigantic Dinosaur bones upon which Prof. Marsh established the genus Atlantosaurus. Other remains of the same animal have been found at this horizon, both to the north and south of Morrison, and also at a corresponding position near Canyon City.

In the white Dakota sandstones and in a fire-clay bed in the middle of the sandstone section there has been found an extensive fossil flora which has been made the subject-matter of a monograph by Prof. Lesquereux, published by the U. S. Geological Survey. The section of Fort Benton shales immediately overlying the Dakota is most clearly seen on the south bank of Bear creek, along the line of an irrigating ditch.

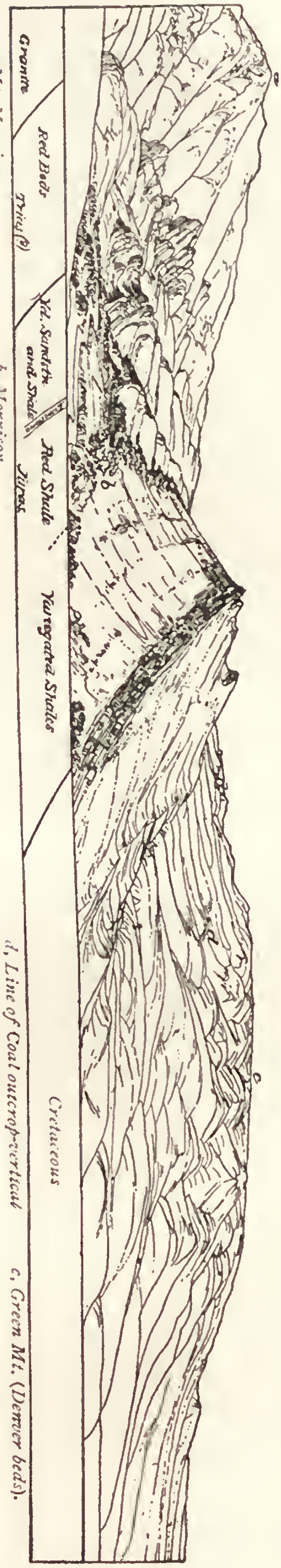


Fig. 26.—Section at Bear Creek.

The small ridge at the base of the Dakota hogback is caused by the Niobrara limestones and the entire section of the Niobrara is very well shown in the part of the section illustrated.

Following the Niobrara comes a great thickness of Fort Pierre shales, which, along Bear creek, have a thickness of over 5,000 feet, while in the section running from the summit of Green mountain, about three miles to the northward of Bear creek, their thickness is reduced to a few hundred feet. From the observed variation in the thickness of these beds, together with the visible divergence of strike in this interval, Mr. Eldridge has established a considerable unconformity between the Niobrara and Fort Pierre.[81]

Above the Fort Pierre come the shales of the Fox Hills in their normal development. At the western base of Green mountain is a small but distinct ridge of the Laramie sandstones (*d*, Fig. 26) in vertical position, containing coal beds, here of less than the normal thickness. This line of the Laramie beds is clearly traceable along the southern slopes of Green mountain, running parallel to the band representing the Fox Hills, and crosses Bear creek at a hill called Mount Carbon

three miles east of Morrison. Here the coal banks have become thicker and have been opened in several mines.

Green mountain will always remain a classic locality for the post-Laramie lake beds which have been named the Arapahoe and Denver formations. In a small ravine on the southwest slope of Green mountain, whose course is almost toward the point of view in the section given, one may see an almost continuous exposure of the Laramie and Arapahoe beds in vertical position. It was in this ravine that the first pebbles of Dakota conglomerate, and other Mesozoic sandstones were detected in the conglomerate, which is the most conspicuous feature of the Arapahoe series. From this ravine the Arapahoe conglomerate can be traced southward in practical continuity to a point several miles south of the Platte canyon, and northward to Golden, although in the latter direction it is less well marked, owing to the smaller size of the pebbles.

The main mass of Green mountain is made up of Denver beds. Contact with the Arapahoe beds is most clearly indicated in the ravine first mentioned and in others on the western slope of the mountain; the lower 200 or 300 feet of the formation are, however, not very continuously exposed in any section. But a characteristic conglomerate composed of dark andesitic pebbles is clearly shown at the western base of the more abrupt slopes of the mountain, and from this horizon to the summit there is an almost continuous section illustrating very clearly the characteristics of the formation. The coarse conglomerates of the upper part of the Denver formation are here so loosely consolidated that the mountain summit and upper slopes are covered with loose boulders, which were not originally identified as belonging to a definite formation in place, but considered drift boulders. For details concerning the exposures of the Denver and Arapahoe formations in Green mountain the reader is referred to the original article [79] on the Denver Tertiary formation and the accompanying map, in which the location of the section ravine and the best exposures are clearly indicated. The outcrops of the Denver formation are shown at intervals along the banks of Bear creek and its junction with Platte river. Many Dinosaur bones, referred by Prof. Marsh to the Ceratopsidæ, have been found in the Denver beds on the western slopes of Green mountain and in the plains area between that and the Platte river.

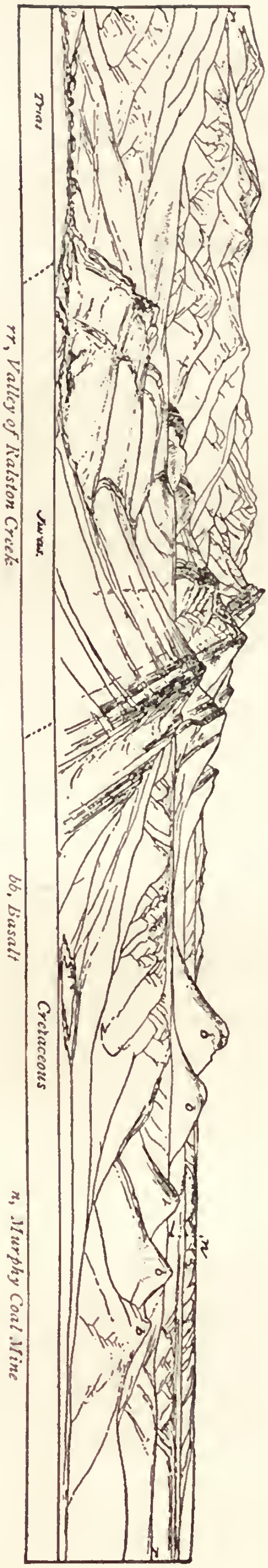
EXCURSION TO GOLDEN.

By Whitman Cross.

Golden lies 10 miles (16 km.) west of Denver, on Clear creek, at the point where it issues from the mountains. The position of Golden corresponds to that of Morrison, except that the elevations separating it from the plains, North and South Table mountains, have an entirely different character from the Dakota ridge of the other locality. The section of the sedimentary rocks exposed at Golden is comparatively very narrow through the thinning of several formations between the red beds of the Trias and the Laramie. Some of the formations, such as the Dakota, entirely disappear from the section at the point where it is crossed by Clear creek.[81]

The first formation to preserve its normal thickness and position in the section at Golden is the Laramie Cretaceous, which here has a thickness of about 800 feet (244 m.), standing in vertical position. The coal measures are well developed, and are explored by several coal mines. An abundant fossil flora has been found in the sandstones adjoining the coal.

To the east of Golden, not more than one mile (1·61 km.) from the Archean foothills, are the two Table mountains, separated by a gorge made by Clear creek in cutting its way to the plains. The Table mountains have a basaltic capping of varying thickness, up to a maximum of 300 feet (91 m.). Basalt protects the soft friable sandstones of the Denver beds, which contain a very well preserved and abundant fossil flora in many horizons. The Denver strata in Table mountain represent the characteristic development of that formation in its lower portion. There are exposures in South Table mountain in the neighborhood of Castle Rock and at the northeastern corner of the mountain.[79]



rr, Valley of Ralston Creek bb, Basalt n, Murphy Coal Mine

Fig. 27.—Section at Van Bibber creek.

Between the Laramie and the Denver beds is a narrow outcrop of the Arapahoe formation, which is, however, exposed in very obscure outcrops in this region. It occurs as a narrow band of steeply upturned strata apparently conformable with the Laramie.

In a wide amygdaloidal zone in North Table mountain there is a succession of zeolites, which have been described in detail.[76] The occurrence is interesting for the distinct succession of species and for the unusual development of certain forms.

In the Dakota hogbacks north and south of Golden are also fire-clay beds. These are used in manufacturing a very fine quality of fire brick, furnace muffles, crucibles, etc. There is also a large manufactory of ornamental brick in Golden, the material used being largely the plastic clays of the Laramie. The Colorado State School of Mines is located at Golden. It has a fair museum, and is rapidly growing.

In Clear Creek canyon, above Golden, are found exposures of the Archean gneisses and schists. At about 6 miles (10 km.) north of Golden, Ralston creek issues from the mountains, cutting across the sedimentary beds and affording another excellent section which very nearly resembles that at Morrison. Fig. 27, p. 441 (after Holmes,) represents the section displayed on the north bank of Van Bibber creek, a small stream north of North Table mountain. This illustrates the section exposed in better detail along the line of Ralston creek, which crosses the field of view along the middle-ground. There is here a great development of the Triassic red beds, the Jura, and the Dakota. There are extensive quarries of the lower sandstones. On the right hand of the figure are seen a number of conical hills of basalt, representing necks or dikes, through which the lavas of Table mountain ascended. The terrace formations of the plains are very clearly represented.

THE GREAT PLAINS OF COLORADO AND KANSAS.

By S. F. Emmons.

From Denver to Kansas City the entire width of the Great Plains is again crossed, which present the same, or even greater, monotony of scenery than where they were crossed on the outward journey in Dakota. Their surface descends in a gentle but imperceptible slope about 10 feet in the mile, or 5,000 feet (1,250 m.) in the 500 miles (800 km.) that lie between these points. There is but little variety of erosional forms. The modern rivers, which in the spring and early summer are rapid, muddy torrents, constantly changing their meandering courses in their wide bottoms, gradually decrease in volume during the summer and autumn, and through the greater part of the year are shallow, inconsiderable streams. There is evidence that the larger of these streams have followed the same general course in early Tertiary times that they do now, for Tertiary deposits have filled them up in some places, and later erosion has not entirely removed these deposits from the sides of the later channels. There is little to be seen of the characteristically glacial topography shown on the more northern route, nor are any typical *mauvaises terres* to be seen along the route of travel. The streams whose valleys are traversed during the night and succeeding day do not have their sources in the Rocky Mountains, as do the Platte and Arkansas rivers, but head in springs between these two rivers and at some distance from the mountains.

The substructure of the Plains in this latitude is formed by strata of Paleozoic, Mesozoic, and Tertiary ages, which lie nearly in position of original deposition, and show no preceptible discordance of stratification between the beds of successive series. The surface is masked to some extent, especially along the more important valleys, by a loess-like deposit which gives great fertility when rainfall is sufficient for cultivation, or when, as near the mountains, a sufficient supply of water may be obtained for irrigation. In general, lower beds in the geological series are disclosed in going east; but as the region has not yet been systematically surveyed, except in limited areas, only the broader general features of its geology are known. The transgression which is so marked in the Appalachians between Paleozoic and Mesozic is not distinguished here. On the contrary, there seems to be a gradual passage, not only in the sedimentation but in the succession of life, from the Carboniferous into the Red Beds of the Trias. Between the latter and

the Dakota Cretaceous, however, the transgression is more distinct, and that between Laramie Cretaceous and Tertiary is very marked. In the area passed over during the night, after leaving the Laramie exposures which form the eastern boundary of the Denver basin, Tertiary beds extend eastward to Phillipsburg which is reached in the early morning. From there to Clay Center, Cretaceous beds furnish the only visible outcrops, the Red Beds of the Trias which come to the surface in southern Kansas not appearing along the line of travel. The coal measures of the Missouri-Iowa coal basin, which also extend into and are of economic importance in Kansas, pass upward into a series of shales and limestones, with a few unimportant sheets of sandstones, the whole containing a fauna of newer facies than that of the uppermost members of the Carboniferous remaining in the Appalachians. These have been commonly referred by local geologists to the Permian, or Permo-Carboniferous. The Tertiary beds which once covered the eastern portion of the plains area have been almost entirely removed by erosion. They are partly replaced by the drift deposits of the ice sheet, whose western margin extended a short distance to the west of the present valley of the Missouri river, where it forms the boundary between the States of Iowa and Missouri on the east and Nebraska and Kansas on the west.

Mr. Robert Hay contributes the following on the surface geology of the Plains in Kansas and Nebraska where traversed by the various railroads:

The geology of the country is substantially the same along these various routes. From the longitude of about 103° 30′ eastward there are two formations that are conspicuous. The highest I call the Plains marl. Though it has variations it is remarkable for its lithologic similarity over vast areas, and samples not to be distinguished from each other could be obtained from the northern plains of Nebraska, the midplains (Platte-Arkansas) region and the Panhandle of Texas. It is argillaceous, arenaceous, and calcareous everywhere, and its varieties are due simply to the predominance of one or the other of its principal ingredients. Where the lime and clay have been weathered out, sand dunes are left. It has few fossils, but horse teeth have been found in it. In at least a part of the plains it is the Equus beds of Cope. Its origin probably began in the Pliocene era and stretched all through Pleistocene time. It forms the smooth floor of the unbroken high prairie of the West. The short gramma and other grasses have given its surface a compact sod that turns the water off it and in time of storm causes rapid flooding of the sandy arroyos and river valleys. On the one hundred and second meridian and from the thirty-fifth to the fortieth parallel it is from 50 to 200 feet deep, increasing in thickness north of the Republican and decreasing eastward. Broken by the plow it makes a fertile soil, and taken from excavations it is of the same quality to the bottom. Vegetation has not been sufficient to more than slightly discolor its surface. There is no black soil on the prairie. Owing to erosion immediately preceding its deposition, it is found in many valleys where, vegetation having since been ranker, the marl is more humus-like under the grass roots. Erosion of the modern

age having made more impression as we proceed east, the narrowing area of the uplands has less of the Plains marl, and east of the ninety-eighth meridian it is only recognized in small isolated areas. Coming east it becomes more and more loess-like and in Nebraska and northern Kansas it merges into that formation, which is typically developed in the bluffs of the Missouri River. In eastern Colorado and western Nebraska and Kansas the Plains marl is usually underlaid by well-defined Tertiary formations. About the one hundred and fourth meridian on both sides of the Platte River these are the White River strata principally, which may be named, from their lithologic character, the Mortar beds. Coming east and south these thin out and give place to the Loup Fork, into which they merge. This last formation has within it beds of conglomerate, but whether as fresh-water lime beds, mortar beds, or conglomerates, the Loup Fork is everywhere a water holder; and this is true also of the thicker White River beds stretching toward Wyoming and northwest Nebraska. The more impervious Plains marl lets the meteoric water percolate slowly through it, and the looser arenaceous or gravelly texture of the White River or the Loup Fork beds holds the water till it is reached by wells from above, or escapes in springs in ravines where erosion has cut sufficiently deep. The ever-present arenaceous character of these Tertiary beds, whether as mortar beds or conglomerates, and their consequent water-bearing capacity have suggested the term Tertiary grit as a designation showing their relation to economic geology. These two formations, the Plains marl and Tertiary grit, make the essential features of the mid-plains geology. The mammalian and reptilian (turtle) fossils of the grit have been described by Marsh and Cope. Some floral remains and fresh-water univalves have also been found. Underneath the marl and grit in all the mid-plain region lie Cretaceous formations. These are all more impervious than the Tertiary grit and so help to make the water-bearing character of that formation more decided.

DENVER TO KANSAS CITY

ITINERARY.

By S. F. EMMONS.*

Station.	Distance.		Elevation.		Station.	Distance.		Elevation.	
	Miles.	Kilometers.	Feet.	Meters.		Miles.	Kilometers.	Feet.	Meters.
Denver *a*	0	0	5,182	1,579	Morganville	469	755	1,233	376
Limon	90	145	5,354	1,632	Clay Center	476	766	1,198	365
Goodland	198	319	3,687	1,124	Broughton	482	776	1,185	361
Norton	304	489	2,270	692	Bala	488	785	1,266	386
Phillipsburg	338	544	1,939	591	Riley	495	797	1,274	389
Gretna	344	554	....	....	Keats	504	811	1,124	343
Agra	349	562	1,756	535	Manhattan	513	826	1,014	309
Kensington	353	568	1,773	540	Zeandale	520	837	1,007	307
Athol	359	578	1,786	544	Wabaunsee	525	845	1,044	318
Smith Center	367	591	1,804	550	McFarland	534	859	1,020	311
Bellaire	373	600	1,866	569	Paxico	538	867	991	302
Lebanon	379	610	1,816	554	Maple Hill	546	879	957	292
Ezbon	386	621	1,829	557	Williard	551	887	912	278
Otego	391	629	1,792	546	Valencia	555	893	904	276
Mankato	399	642	1,787	544	Topeka *b*	566	911	877	267
Montrose	406	653	1,658	505	Grantville	572	921	812	247
Formosa	411	661	1,515	462	Newman	578	930	796	243
Courtland	416	669	1,499	457	Medina	580	933	789	240
Scandia	422	679	1,431	436	Williamstown	585	941	789	240
Belleville	436	702	1,514	461	Lawrence *c*	596	959	763	233
Cuba	441	710	1,588	476	Linwood	607	977	733	223
Agenda	447	719	1,409	429	Bonner Springs	618	995	739	225
Clyde	455	732	1,295	395	Armstrong	633	1,019	690	210
Clifton	461	742	1,265	386	Kansas City *d*	635	1,022	750	229

a Population, 106,713. *b* Population, 31,007. *c* Population, 9,997. *d* Population, 132,716.

From **Denver** to **Limon** the train runs on the tracks of the Kansas Pacific Railroad, first eastward, then bending to the south-southeast. The main line of the Chicago and Rock Island Railroad starts from **Colorado Springs**, and in its course to **Limon** runs a little north of east along the southern base of the mesa region which forms the divide between the waters of the Platte and Arkansas rivers. These mesas have not yet been systematically studied, but as far as known consist

*From notes furnished by R. Hay and R. T. Hill.

mainly of beds of the Tertiary system already described as the Monument Creek series, which may include several formations.

A few miles east of **Denver** the Denver beds are lost to view, and the surface is formed by those of the Laramie Cretaceous, also occupying a practically horizontal position. The higher elevations to the southward, especially as **Limon** is approached, are occupied by remnants of the Tertiary formations, while the broader valleys often contain local developments of more recent formations.

From **Limon**, which is on the Big Sandy creek, a tributary of the Arkansas River, the road takes an easterly course passing on to the head waters of the Republican river, one of the important streams which takes its rise in springs on the plains at a considerable distance from the mountains. Eighteen miles west of **Goodland** it passes into the State of Kansas, and follows the northern edge of the divide between the drainage of the Republican and Solomon rivers nearly to **Phillipsburg**, which is within the drainage system of the latter stream.

The surface of the country between **Limon** and **Phillipsburg** is, presumably, mostly covered by Tertiary formations of as yet undetermined age, the earlier being a grit or series of sands and conglomerates (supposed to be Miocene), with a recent marl or loess deposited on its eroded surface. The latter is well seen near **Norton, Phillipsburg,** and **Smith Center.** Wherever older Mesozoic outcrops are exposed by erosion of these overlying beds, they are found as a rule to be successively older as one goes farther east.

Phillipsburg is situated near the eastern edge of the great Tertiary plains. The Tertiary beds which once stretched east of it have been in great part removed by the drainage system of the Republican, Solomon, and Smoky Hill rivers. Just before reaching it a prominent mound, known as the (inverted) Bread Bowl, is formed by a protecting top of the hard, conglomerate grit of the Miocene. Fifteen miles to the north, at Long Island, in what are called the mortar beds of the Miocene, is the bone bed from which Prof. O. C. Marsh obtained many mammalian remains.

Farther east, in Smith county (**Smith Center,** county seat), the beds of Colorado Cretaceous are seen; first, the soft magnesian Niobrara limestone, then occasionally a blue shale. At the crossing of the Republican River, near **Scandia,** the bluffs are of Fort Benton age.

Near **Belleville,** and south from there, the sandstones and colored shales of the Dakota are passed over, but the outcrops are few and inconspicuous.

Although no outcrops of Mesozoic beds lower than the Dakota have been recognized, red sandstones, which are presumably Triassic, have been pierced in boring for salt along the line of the Kansas Pacific Railway in Ellsworth County, still farther southward, in about the mid-

dle of the State. The salt measures are barren gray beds above the highest light-colored Permian, and contain beds of rock salt from 100 to 200 feet in thickness.

The route from **Clay Center** to **Kansas City**, and also that running northeastward across Nebraska to Omaha, lies mainly upon limestones and shales of Permian and Carboniferous age.

Between **Clyde** and **Clay Center** the road follows a valley which had been enormously widened in Quaternary times and cut below the level of the plains, as preserved in the dividing ridges between the streams. Leaving this valley at **Clay Center** the road ascends the divide between the Republican and Blue rivers, and enters upon the Paleozoic area. The underlying rock is now the horizontal yellow limestone of the Permian, to whose existence the persistence of the divide is due.

The road enters the valley of the Kansas or Kaw River at **Manhattan.** Twenty miles up this river, in a southwesterly direction, on a point overlooking the junction of the Republican and Smoky Hill rivers and within the Fort Riley military reservation, there is a stone monument marking the geographic center of the United States as determined in 1880.

At **Manhattan** a good cross section of the Kansas Valley is obtained. On the opposite side of the river are heavy beds of orange-colored loess. Near this station, and again near **McFarland**, are outcrops of the flint beds, which are a conspicuous feature of the Permian throughout several counties. The road now passes into the Coal Measures, which constitute the prevailing formation of the uplands as far as **Kansas City.** Drift boulders of red quartzite from Minnesota, supposed to come from the drift in northern Kansas, are seen close to the road before entering **McFarland.**

Between **Topeka** and **Kansas City** drift is abundant, and its presence is shown by the form of the low hills to the north of the road.

At **Lawrence** a considerable morainal deposit is seen on both sides of the river, across which it once probably formed a dam.

THE PRAIRIES.

By W J McGee.

When first explored by white men the eastern United States was wooded; much of the interior was woodless—the "prairie" of the French explorers, whose designation promises to outlive the condition described by the term; still farther westward lay the Great Plains, with which the prairies merged, and beyond lay the mountains. During this day's journey the route traverses a representative prairie land—the identical tract to which the name was originally applied. Now it is diversified, sometimes by natural groves or belts of woodland along the rivers, sprung up since the day of aboriginal prairie fires ended; elsewhere by artificial groves, hedges, and wind-breaks, such as abound over most of the interior region.

The prairie soil is commonly the long-weathered surface of one of the two great glacial drift sheets, antedating the terminal moraine. Generally the drift grades upward into a loam, sometimes loess-like, but more commonly displaying the characters of clay. Near the Mississippi, however, this loam deposit has developed into a fairly well-defined loess, which is not, however, so distinctive or so abundantly developed as on the Missouri. In the interior the loam is commonly so thin that drift boulders may be seen approaching the soil in the railway cuts, and not infrequently they lie scattered over the surface in considerable numbers. All, or nearly all, of these boulders are far-traveled erratics, carried down from near or beyond the northern boundary of the United States.

The relief is low, the surface undulating gently; the configuration is the product of faint hydrodynamic sculpture, for the most part directed by the antecedent glacial configuration and by the temporary waterways born of the melting ice. It is noteworthy that this surface, primarily ice fashioned, is now so far modified by waterwork that practically the entire surface is well drained. Marshes occur only rarely and lakes never. In this respect the extra-morainal surface is strongly distinguished from the intra-morainal area, in which lakes abound and marshes are innumerable.

FROM KANSAS CITY, MISSOURI, TO CHICAGO, ILLINOIS.

ITINERARY.

By W J McGee.

Station.	Distance.		Elevation.		Population.	Station.	Distance.		Elevation.		Population.
	Miles.	Kilometers.	Feet.	Meters.			Miles.	Kilometers.	Feet.	Meters.	
Kansas City	0	0	750	229	132,716	Bureau	404	650	670	204	....
Cameron	53	84	1,022	301	....	La Salle	419	674	665	203	9,855
Gallatin	75	121	......	.....	....	Ottawa	434	698	688	210	9,985
Jamesport	84	135	......	.....	....	Morris	456	734	722	220	....
Belknap	210	338	887	267	....	Joliet	478	769	540	165	....
Muscatine	306	492	562	165	11,454	Blue Island June	501	806	807	246	....
Davenport	335	539	595	181	26,872	Auburn June	510	821	795	212	....
Rock Island	337	542	470	143	13,634	Englewood	511	822	603	183	....
Moline	339	546	773	236	12,000	Chicago	518	833	594	181	1,099,850

At **Kansas City** are drift and loess, both resting on Carboniferous beds. The loess is here, as elsewhere, a clayey loam, distinguished by its tendency to cleave vertically and to stand in perpendicular walls as a result of erosion, thus producing characteristic topographical forms.

The road now takes a northwesterly direction through the State of Missouri. After leaving **Kansas City** the loess continues as a conspicuous feature for miles, grading into loam and then into drift. The substructure is formed by upper Carboniferous beds, which contain coal seams of variable thickness and considerable extent, but which have not been exploited on account of the proximity of the Iowa-Missouri coal basin, in which the seams of the middle Coal Measures are found at less depth. Midway between the Missouri and the Mississippi the route crosses this basin, and gradually descends geologically over the lower Coal Measures and the sub-Carboniferous formations, the latter being well developed about the Des Moines river.

At **Muscatine** the road reaches Mississippi river, whose valley it follows to the crossing at **Davenport**.

The subterrane from the Mississippi to Lake Michigan is Paleozoic, including Carboniferous, Devonian, and Silurian rocks. About **Davenport** and **Rock Island** the Carboniferous rocks are brown sandstones, commonly considered to have been deposited in outlying basins near the shore line

of the middle Carboniferous sea; but within 25 miles east of Mississippi river the rocks come to resemble more closely those characteristic of the Coal Measures of the Illinois-Indiana basin. The sandstones near the river, and the shales and limestones (with a few coal seams) of the interior, rest unconformably on the older strata; for the calcareous series of deposits, commonly referred to the sub-Carboniferous, is absent, and the Devonian, broadly developed in Iowa, soon fails, leaving the Carboniferous and Silurian strata nearly or quite contiguous.

On approaching **Davenport** the railroad passes through deep cuts in Pleistocene deposits, which afford interesting sections. The uppermost deposit is loess, somewhat more clayey than that of Missouri river, yet abounding in similar fossils; its thickness ranging from 10 to 30 feet. At its base it commonly becomes gravelly or grades into an attenuated drift sheet; and loess and drift alike rest on an ancient soil, or "forest bed," which has yielded not only abundant remains of coniferous woods, but also bones and tusks of the elephant. Below lies a dense, tenacious drift sheet, representing the earliest well-defined ice invasion of the Pleistocene.

Between **Davenport** and **Rock Island** the Mississippi flows in what may be styled, for that stream, a contracted gorge, half a mile to a mile in width. This gorge opens immediately below the cities; upstream it extends for some 25 miles to the town of Le Claire. Throughout this stretch of relatively narrow channel the current is exceptionally strong, particularly at the upper and lower extremities. Thus the terms "Rock Islands Rapids" and "Le Claire Rapids" have long been familiar to the pilots and captains of the packets plying between St. Louis and St. Paul, and, indeed, to other rivermen. Formerly the rocky islet, from which the Illinois city takes its name, was separated from the mainland of Illinois by a navigable channel, and indeed represented nothing more than the largest of a series of "reefs" rising from the river bottom. Subsequently the Iowa channel was deepened and the Illinois channel was finally dammed to afford waterpower for the United States Arsenal located upon the island.

The only rocks exposed in the immediate vicinity of **Davenport** and **Rock Island** are Devonian; they are fossiliferous, and, for the most part, have been correlated with the Hamilton of New York; but their exact position in the geological scale can not be said to be finally determined. Exposures of brown Carboniferous sandstone occur within a few miles of both cities.

A few miles east of **Rock Island** the railroad approaches and finally crosses Rock River, which, it may be observed, flows in a disproportionately broad gorge. Moreover, it may be noted that this valley bifurcates, sending its principal arm northward to be occupied only by a trifling stream, while the narrower is marked by the course of Rock river.

This broad valley represents one of a plexus of channels formed by the floods derived from the melting ice about the close of the Pliocene; it is the *Marais d'Ogee* of the French missionaries, which, traced against the general direction of river flow, extends northeastward and then northward for 40 miles, where it divides once more, this time into three branches. The smallest of the branches coincides with the present course of the Mississippi about Clinton; the next in size coincides with the Wapsipinnicon River for 50 miles; and the principal branch diverges from the Wapsipinnicon a few miles above its mouth and then cuts directly across the interior of eastern Iowa to reunite with the Mississippi at the mouth of the Maquoketa, 100 miles (by river) above **Rock Island.**

East of the plexus of ancient channels the road traverses one of the low divides characteristic of northern-central Illinois—a typical prairie land. On approaching Illinois river the surface becomes more rugose, and rock outcrops appear. About **La Salle** and **Ottawa** the river bluffs are 100 to 200 feet high, and expose a variety of formations within a limited area, ranging from the coal-bearing Carboniferous through the Niagara (the characteristic Upper Silurian formation of the interior) and down to the Oneota (or "Lower Magnesian)," or the St. Peter. In this vicinity the structure is more complex than elsewhere in Illinois save in two localities, i. e., at the mouth of Illinois river, and near the confluence of the Ohio; it is a region of decided deformation of unconformable strata, afterward planed down to base level. Noteworthy fossil localities occur in the vicinity. The rocks are mantled with glacial drift so deeply that exposures are rare, except in the river bluffs.

Nearly all the way from **Ottawa** to **Chicago** the route traverses monotonous prairie land, faintly relieved here and there by moraines, inconspicuous in comparison with those of the northern route. There are few rock exposures, the most notable being at **Joliet**, where there are extensive quarries. The subterrane from **Ottawa** to **Chicago** is deeply buried beneath the drift, but is probably almost wholly Upper Silurian, and chiefly the interior represensative of the New York Niagara.

CHICAGO TO NIAGARA FALLS.

ITINERARY.

By G. K. GILBERT.

Station.	Distance. Miles.	Distance. Kilometers.	Elevation. Feet.	Elevation. Meters.	Population.	Station.	Distance. Miles.	Distance. Kilometers.	Elevation. Feet.	Elevation. Meters.	Population.
Chicago	0	.....	594	181	1,099,850	Schoolcraft	146	235	878	267	....
Elsdon	8	13	.....	.....	....	Battle Creek	175	282	823	251	....
Blue Island Junc	20	32	.....	.....	....	Lansing	220	354	836	256	13,197
Harvey	23	38	.....	.....	....	Durand	252	406	794	241	13,102
Thornton Junc	25	42	.....	.....	....	Port Huron	335	539	584	178	....
Maynard	31	51	.....	.....	....	Sarnia	336	541	587	179	13,543
Griffith	36	59	.....	.....	....	London	397	639	806	246	....
Redesdale	39	64	.....	.....	....	Woodstock	425	685	951	291	....
Ainsworth	45	74	.....	.....	....	Harrisburg	453	731	734	224	....
Sedley	50	82	694	212	....	Dundas	.....	.....	.....	.....	....
Valparaiso	55	90	806	245	....	Hamilton	472	760	255	78	....
South Bend	100	162	713	217	21,819	Niagara Falls:					
Mishawaka	104	167	721	220	....	Canadian side	516	830	573	174	....
Cassapolis	122	196	880	268	....	American side	518	841	574	175	....

Leaving **Chicago** at 3 o'clock p. m., we cross before night the corners of Illinois and Indiana and a part of Michigan. In passing about the head of Lake Michigan the underlying Silurian and Devonian rocks are not seen, but only the Champlain sands accumulated by winds and waves at the end of the lake when its water stood at higher levels. The winds are still busy with them, piling them in traveling dunes which block the drainage, converting much of the land into marsh.

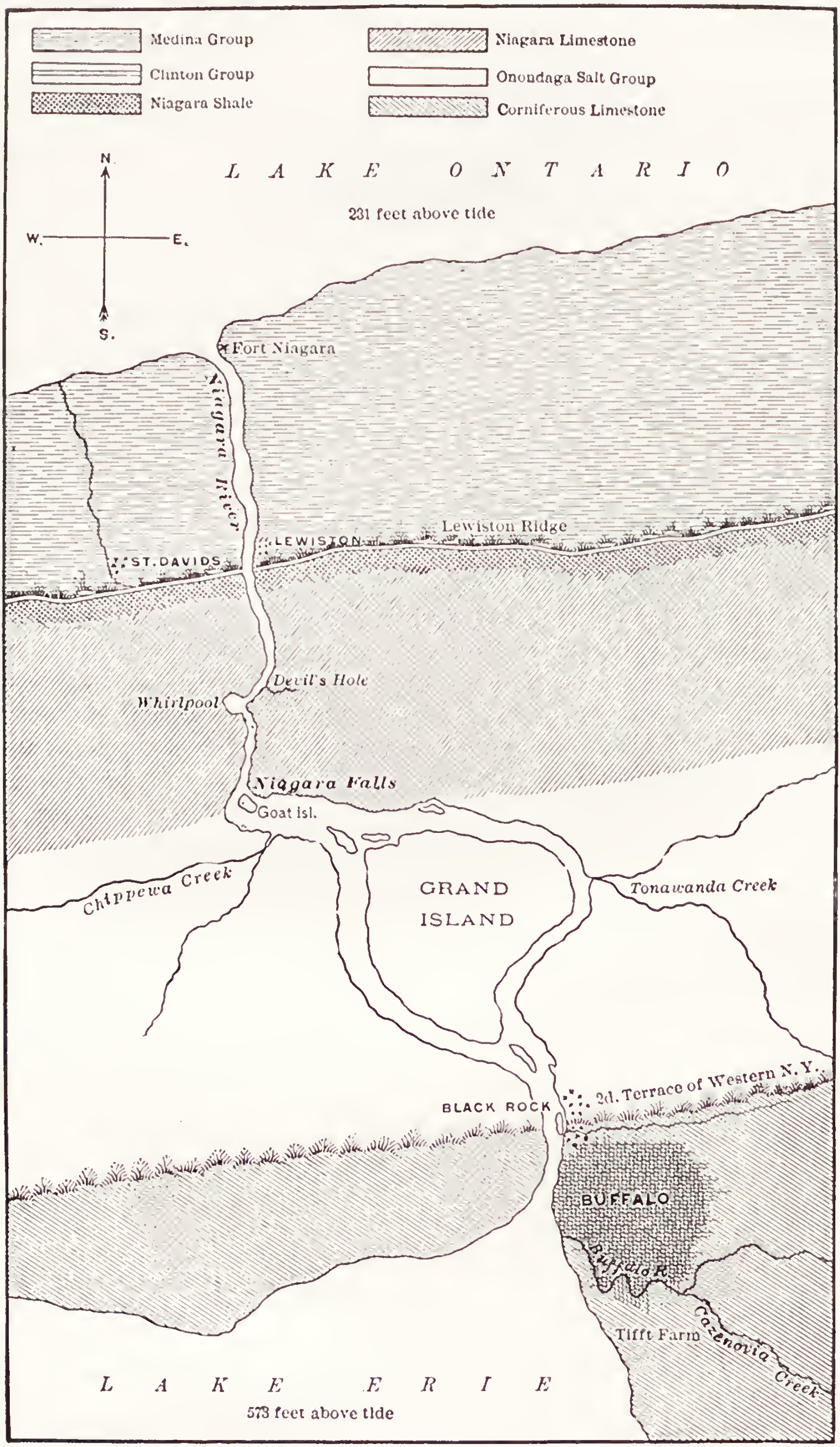
Soon after entering the State of Michigan we pass from Devonian to Carboniferous terranes, entering the Michigan coal basin. That portion of the State lying between lakes Michigan and Huron, called the Lower Peninsula, is characterized by a synclinal basin of gentle dips, carrying the Silurian rocks below the level of the sea and bringing the Carboniferous below the plane of denudation. In this structural basin brines are preserved, on which an important salt industry is based.

It is of interest to note the relation of the Michigan syncline to the general structure and to the basins of the Laurentian lakes. Throughout a large region, including the lake district, the general strike of outcrops is east and west, the older rocks lying at the north and the

newer at the south. In latitudes 85° to 87° a double interruption to this arrangement occurs. The line of Devonian outcrop swings 250 miles (400 km.) southward in a great loop about the Cincinnati upward arch; the Silurian outcrop swings an equal distance northward about the Michigan downward arch; and between the two arches there is a belt in which the dips are northward. The most resistant members of the Paleozoic are the Trenton limestone, at the base of the Silurian, and the Niagara limestone, near the top of the same system. Between these are shales and soft sands of the Utica, Hudson River, and Medina series, and above the Niagara are equally soft shales of the Salina, Hamilton, and Chemung series. The basins of lakes Michigan and Huron are carved from the monocline of soft rocks above the Niagara, where it sweeps around the Michigan syncline, and are thus made to embrace the coal basin. Lake Erie lies in a trough carved from the same monocline where its trend is nearly normal. Lake Ontario lies in the monocline below the Niagara limestone, where its course is normal, and the same monocline, where it curves about the Michigan coal basin, holds Georgian and Manitoulin bays, dependencies of Lake Huron, and Green bay, a dependency of Lake Michigan. It is believed that the excavation of the basins was accomplished partly by rains and rivers during pre-Pleistocene and interglacial times when the district stood at a higher level than now, and partly by Pleistocene ice currents. As to the relative importance of the two agencies geologists are not agreed, and it may safely be said that the determination of the question belongs to the future.[82, 83]

The surface features in Michigan depend largely on the drift, consisting of ground moraine traversed by numerous marginal moraines. Lakelets, ponds, and swamps are numerous. On both sides of the St. Clair river, connecting Lake Huron with Lake St. Clair, the till is overlain by laminated Champlain clays, here called Erie clay, and the surface of the country is smooth.

From **Sarnia** to **Hamilton**, in the Province of Ontario, Dominion of Canada,[84] the route continues on the eastern limb of the Michigan syncline, gradually descending in the geologic scale through the Devonian and Upper Silurian. The Hamilton shales are succeeded by the Corniferous limestone near **London**; the Onondaga follows, and at **St. George** the Guelph, an upper member of the Niagara limestone. The main mass of the Niagara is met at **Capetown**, the underlying Clinton at **Dundas**, and the Medina at **Hamilton**. Nearly the whole country is heavily sheeted by drift deposits. The Erie clay, which occupies the entire surface for the first hundred miles and appears at intervals beyond, is a laminated calcareous clay, with erratic pebbles and bowlders, but no fossils, apparently the deposit of a great lake at the margin of the ice. Smaller bodies are traversed of the Algoma sand



MAP OF NIAGARA RIVER FROM LAKE TO LAKE.

and the Artemisia gravel, deposits likewise of great extent and containing material of distant origin, but not yet satisfactorily interpreted.

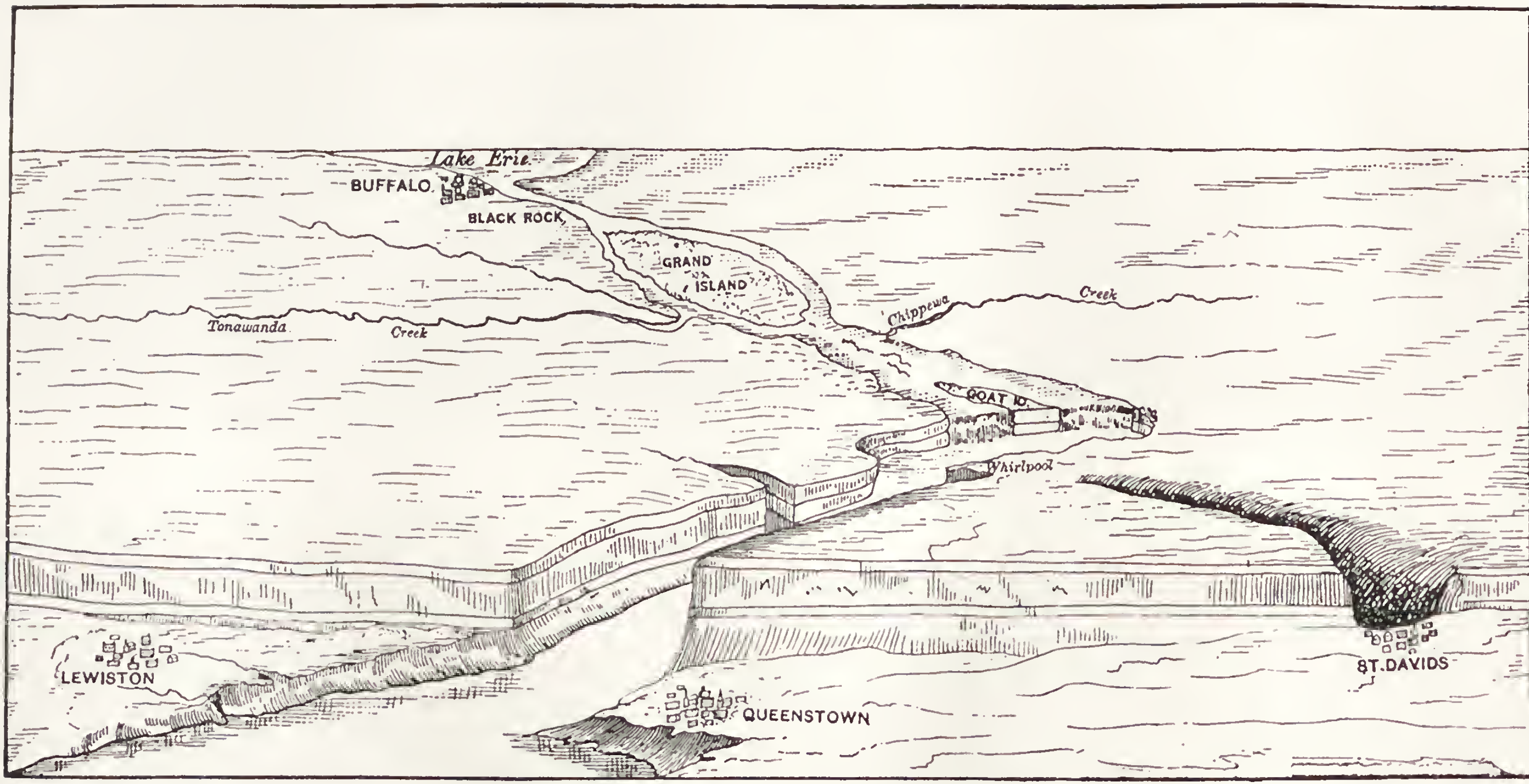
From **Hamilton**, at the head of Lake Ontario, the train runs eastward over a broad escarpment of red Medina shales (Upper Silurian) superficially sheeted with till and clay similar to the Champlain. At the left lies Lake Ontario; at the right the plain rises to the foot of an escarpment several hundred feet in height, which is capped by Niagara limestone. The plain is contoured by an old shore-line of Lake Ontario, known as the Iroquois beach. In the city of **Hamilton** at the head of the lake this beach takes the form of an immense free spit or embankment more than 100 feet in height. At other points it appears as a low barrier of sand and shingle, and yet at other points as a low bluff undermined by the waves. Since the date of the Iroquois beach the lake water has also stood at a level lower than the present, and during the period of low water the small streams which traverse the plain opened valleys in the lacustrine clay. These valleys are now partly occupied by lake water, being marked by small bays, to each of which a small stream is tributary.

Leaving the littoral plain, the train climbs the escarpment, so as to approach **Niagara falls** on the plain constituted by the upper surface of Niagara limestone.

NIAGARA FALLS. 85, 86.

By G. K. Gilbert.

The Niagara river flows northward from Lake Erie to Lake Ontario. The region is floored by Paleozoic strata, which dip at a low angle toward the south or upstream. Two limestones are of physiographic importance, the Corniferous and the Niagara. Beneath the Corniferous and above the Niagara are several hundred feet of shaly beds (Onondaga salt group), yielding readily to erosive agencies. Beneath the Niagara limestone are feebly resistant beds, known as the Niagara shale, the Clinton beds, and the Medina shale. As a result of this alternation of hard and soft strata the district consists topographically of two sloping plateaus, each limited toward the north (downstream) by an escarpment. The Corniferous escarpment, lying near Lake Erie, is relatively low; the Niagara escarpment is about 200 feet high and faces toward Lake Ontario. Lake Erie rests on the Corniferous plateau, and the Corniferous limestone determines the height of its water surface. Across this limestone the river flows with a rapid current. In the region of shales beyond it travels more slowly and spreads out broadly. It traverses the plateau of Niagara limestone in a narrow canyon, at the head of which is a cataract. The passage through the canyon is



BIRD'S-EYE VIEW OF THE NIAGARA RIVER.

by a series of violent rapids, the water tumbling over a rough bottom composed of limestone blocks fallen from the walls. Beyond the Niagara escarpment the river traverses a low plain with deep and quiet current.

In the walls of the canyon the strata are finely displayed. At the top the Niagara limestone has a thickness of about 80 feet (24 m.) near the cataract, and this gradually diminishes to the edge of the plateau, the difference being due to the general degradation of the surface. The full thickness of the limestone previous to erosion was about 140 feet (42 m.). Beneath the limestone is the gray Niagara shale, about 80 feet (24 m.) in thickness; then come the Clinton beds, gray limestones and shales, with a sandstone at base, and a total thickness of 35 feet (10 m.), and finally the Medina shales and sandstones, here consisting chiefly of red arenaceous shale rarely interrupted by ledges of sandstone. At the foot of the cataract, the Clinton is near the water's edge; northward it rises at the rate of 25 feet (7 m.) to the mile, and the river falls at a much more rapid rate, so that a basal exposure of the red Medina increases rapidly from the cataract to the escarpment. All these beds, except the Niagara limestone, are in places more or less obscured by talus, but the complete section can be seen on the American side, just below the lower suspension bridge.

The basins occupied by Lake Erie and Lake Ontario had a different system of drainage previous to Pleistocene time, and were remodeled by the work of the ice sheet, which modified the geography of the Great Lake region in important ways. Some regions of soft strata suffered notable erosion, and the old drainage lines were in many cases completely obliterated by deposits of the glacial drift. When the ice melted the waters were compelled to find new ways, and the drainage of the glaciated region was imperfect or immature, in that it included an immense number of lakes, large and small. Lake Erie and Lake Ontario came into existence at that time, and so did the Niagara river.

The erosion of the Niagara gorge from the escarpment back to the cataract is therefore a post-glacial work, and as a measure of post-glacial time it has attracted great attention. The length of the gorge eroded, about six miles, is readily measured. The present rate of erosion by the cataract is susceptible of measurement, and observation has already given it a value with valid claims for consideration. From a survey made in 1842, and subsequent surveys made in 1875, 1886, and 1890, it appears that the central portion of the main cataract, the Horseshoe fall, is receding 4 or 5 feet per annum, and that the American fall, which carries much less water, is receding much less rapidly. For those who are willing to postulate a uniform rate of recession through the whole extent of the gorge, it is easy to estimate the age of the river from these data, but there are important reasons for questioning the validity of the postulate.

The continuity of the geologic section in the walls of the canyon is interrupted at one point on the Canadian side. At the locality known as the Whirlpool there is an embayment of the wall, and at the head of that embayment a body of drift is exposed from top to bottom of the bluff, replacing the Paleozoic strata. How much deeper it extends is not known, but the river has here gouged out a deep pool, in which the current is temporarily slackened, and it appears probable that this excavation was in the soft drift. Associated with this feature is an embayment of the Niagara escarpment, near the town of St. Davids, not far away. For the space of a mile the limestone cliff disappears, and is partially replaced by glacial drift. It is believed that this embayment and the preglacial cavity at the Whirlpool constitute parts of the same preglacial valley, a valley opening to the northward and terminating southward within the present river canyon, between the Whirlpool and the cataract. So far as this valley extended the river had an easy task, for its canyon was already dug.

On the other hand, it is doubted that the river has at all points been able to work as rapidly as now. The height of the Falls is about 160 feet (48 m.); the pool below the cataract has a depth, at the nearest point where sounding has been successful, of 185 feet (56 m.). This great depth of pool appears to be essential to rapidity of recession, for under the American fall there is no pool and there the recession is slow. But the river has a depth comparable with that of the pool for only a mile or two below the cataract, and at most other points the present cross section renders it improbable that a deep pool was ever formed. It is surmised that at such points the rate of recession may have been slow.

Accordant with this view is the hypothesis, not yet fully tested, that all of the upper lakes, except Lake Erie, once found discharge to the St. Lawrence river by other routes, so that for an unknown fraction of postglacial time the Niagara river drained a district only one-eighth as large as that which it now drains.

The train approaches the Niagara falls from the Canadian side across the suspension bridge, and follows the American bank to the village of Niagara Falls, where it halts for the day. One can conveniently cross again to the Canadian side by the steamer *Maid of the Mist*, or by the upper suspension bridge, and the geologist will wish to see the cataract from both sides and from the river brink below. Goat island, which divides the American fall from Horseshoe fall is reached by a bridge from the American shore, and a spiral stairway leads one thence to the water's edge between the two falls. At the head of this stairway guides and waterproof suits can be secured for a visit to the Cave of the Winds, in which one passes beneath a sheet of falling water constituting a portion of the American fall. The path lies partly on talus,

partly on limestone ledges of the Clinton, and partly on fallen blocks of Niagara limestone. From the Canadian side one can enter a tunnel dug in the Niagara shale, and follow it to a point beneath the Horseshoe fall, whence he can look out at the descending water. At numerous points farther down stream stairways, elevators, and inclined railways are constructed to enable the visitor to reach the water's edge. Those of most value to the geologist are on the American side at the Whirlpool Rapids, and on the Canadian side at the Whirlpool. From the latter a few minutes' walk takes one to the mass of drift filling the preglacial channel, and its contact with the older rocks can be seen.

The accompanying sketch (Fig. 28) was made by M. Golliez, of the visiting geologists.

FIG. 28.—The Whirlpool of the Niagara River.

NIAGARA FALLS TO NEW YORK CITY.

ITINERARY.

By Chas. D. Walcott.

Station.	Distance. Miles.	Distance. Kilometers.	Elevation. Feet.	Elevation. Meters.	Population.	Station.	Distance. Miles.	Distance. Kilometers.	Elevation. Feet.	Elevation. Meters.	Population.
Niagara Falls	0	0	574	175	....	Kingston	362	583	185	56	21,261
Buffalo	22	35	624	190	255,664	Milton	383	616	10	3	....
Bergen	74	119	575	174	....	Newburg	394	634	31	9	23,087
Genesee Junction	87	140	524	160	....	Cornwall	398	640			....
Rochester	91	146	494	151	133,896	West Point	403	649	8	2	....
Newark	121	195	436	133	....	Ft. Montgomery	408	657	8	2	....
Port Byron	147	236	403	123	....	Stony Point	416	669			....
Syracuse	172	277	400	122	88,143	West Nyack	426	686			....
Canastota	193	311	434	132	....	Tappan	432	695	75	23	....
Utica	219	352	523	159	44,007	Bergenfields	439	706	66	20	....
Frankfort	229	369	399	121	....	Hackensack	443	713	47	14	....
Little Falls	241	389	.....	.....	....	Weehawken	451	726	7	2	....
South Schenectady	298	480	349	106	....	New York City, (foot of Jay street)	....	.....	.....	.....	1,515,301
Coeymans Junction	322	518	180	55	....						
Catskill	340	547	97	30	....						

This day's journey is over a region classical in the annals of the development of North American geology. It was along this line that Hall, Emmons, Vanuxen, Mather, and Conrad conducted their investigations, the results of which are published in the first four volumes of the geology of New York and in the annual reports which preceded them. The nomenclature established by them, on the basis of stratigraphy and paleontology, became a part of American geologic science that was extended from State to State by subsequent surveys.

From **Niagara Falls** to the valley of the Hudson at **Schenectady** there are no marked topographic features; the country is undulating, and the route crosses the slightly southward dipping rocks of Lower Devonian, Silurian, and Lower Silurian (Ordovician) age. They are for the most part subjacent to heavy deposits of drift, although numerous fine sections are shown in the various streams that flow in the north and south drainage lines across which the train passes.

From **Schenectady** to **Newburg** the valley of the Hudson River is open and broad, and its undulating surface constitutes part of an ancient base-level, originating in Tertiary time. Afterward continental elevation led the river to corrade its channel deeply, so that the immediate valley of the river lies several hundred feet below the plain of the general valley. The rocks in which this plain is carved are Lower Silurian in age, including the Hudson River, Utica, and Trenton series. They are greatly disturbed, and beautiful sections are shown on the cliffs and in the railroad cuts. Shaly portions have received a cleavage structure, and metamorphism has extended so far that through considerable areas the several series have not yet been discriminated. Uplands visible at the right are due to the superior resistance of the horizontal Lower Helderberg limestone, and loftier uplands seen beyond them are due to the endurance of the Catskill sandstones. The mountain from which the name Catskill (Kaaterskill) is derived is a conspicuous feature at the right (west). At **Newburg** the Trenton limestone occurs with but little alteration, and just beyond it the train enters the area of crystalline schists, to which the mountain range known as the Highlands belongs.

The train then passes through the gorge of the Highlands, keeping close to the water's edge. Above it the old base level plain holds place as a terrace within the gorge.

Beyond the gorge glimpses are obtained of disturbed and altered Paleozoic rocks, and then the train approaches the Palisades, a ridge of trap, originally a sheet or dike injected in the great New Jersey series of red shales and sandstones commonly referred to the Trias. This ridge borders the lower portion of the Hudson on the west for many miles, and at its northern end swings westward. The railroad, passing through the curved northern extremity by a tunnel, follows the western base of the ridge for more than half its length, and then by another tunnel reaches its eastern base and the bank of the river opposite New York.

In passing from **Niagara Falls** to **Buffalo** the train crosses the southern outcrop of the Niagara limestone, the entire width of the Onondaga Salt group, and enters upon the Corniferous limestone of the Lower Devonian. Turning eastward it passes over the latter formation for about 50 miles, when it recrosses the Onondaga Salt group and continues on the Niagara limestone to **Rochester**. From a little distance east of **Rochester** it follows the Onondaga Salt group for over 100 miles, when it crosses the thin eastern extension of the Niagara limestone and the broad development of the Clinton formation before entering upon the Utica and Lorraine shales, upon which it follows for 105 miles except at **Little Falls**, between **Utica** and **Schenectady**, where

a spur of bedded Algonkian gneiss crosses the line of the railroad; a fine geologic section is exposed along the cuts and the Mohawk River.

The Onondaga, Niagara, and Clinton terranes have been fully described by the veteran geologist and paleontologist, James Hall, and the two latter terranes are mentioned in this Guide as they are seen in the canyon of the Niagara. The immediate subjacent formation, as it occurs in the vicinity of **Utica**, includes 800 feet of argillaceous shales in which numerous sandy layers occur near the summit. The lower 710 feet is the Utica formation, and the upper 90 feet the equivalent of the Lorraine shales and sandstones. The Trenton limestone has a thickness of about 150 feet at **Little Falls**, and the immediately subjacent Calciferous sandrock, 190 feet. A thin bed of sandstone and shale just above the Algonkian gneiss has been referred to the Upper Cambrian (Potsdam sandstone) zone, but on evidence that is not conclusive. A fine section of the bedded Algonkian gneisses is shown in the cliffs below the sandstones, and in the river, at the upper end of the narrows, a massive gneiss or granite is to be seen. The almost horizontally bedded Algonkian strata, although crystalline, have frequently been taken to be the downward extension of the superjacent Calciferous formation. Other exposures of the Algonkian, Calciferous, and Trenton terranes occur in the cliffs of the northern side of the valley, between **Little Falls** and **South Schenectady**, while with slight exception the hills on the south side are formed of the Utica shale, with the Trenton limestones at the base.

Turning southeast from **South Schenectady** the road enters the valley of the Hudson and an area where the geologic structure is entirely unlike that passed over from **Niagara Falls** to **South Schenectady**. The Silurian (Ordovician) rocks are upturned, compressed, and more or less broken by the westward thrust of the masses of rock disturbed by the crumpling and folding of the strata of New England. Within the valley there remains to be solved one of the most complicated local geologic problems in North America geology. The higher, outer western sides of the valley are formed of the horizontal Lower Helderberg limestones, with a thin band of the Niagara corralline limestone, beneath which a great thickness of alternating sandstones and shales extend down to a limestone, found in deep wells at 3,475 feet beneath the upper limestone. It is this series of shales and sandstones that are so plicated and altered in the valley to the eastward. As far as known there are no exposures of the undisturbed strata below a point 600 feet beneath the Helderberg limestone. The upper 600 feet exposed has been correlated with the Lorraine, the limestones at the bottom of the deep wells with the Trenton, and the strata between with

the Utica and Lorraine, or all above the supposed Utica, just above the limestone, with the "Hudson River group," of the New York Survey. As the latter occurs out in the valley it contains a strongly marked graptolitic fauna, usually called Normans Kill fauna. This fauna is considered by Prof. Lapworth to be of about Trenton age and pre-Utican—a view sustained by Mr. Ami in his studies at Quebec and by Dr. Gurley in his review of the graptolitic faunas. Certain it is that the graptolitic fauna is not the same as that of the Utica shale of the Mohawk Valley, as has been advanced by Hall, Whitfield, and Walcott. The term Hudson has been applied to these beds between the Lower Helderberg limestone and the supposed Trenton limestone beneath, and the Lorraine and Cincinnati formations correlated as equivalent. This can not be done logically to-day, for the series of shales and sandstones, with occasional interbedded lentiles of limestones, includes all the formations from the Calciferous to Lorraine inclusive. It is, as stated by Sir William Logan, practically the equivalent of the Quebec group, although it includes more at its upper limit in taking in the Lorraine strata beneath the Lower Helderberg limestone.

The sedimentation on the outer limits of the eastern side of the valley includes the Berlin grits and great thicknesses of interbedded purple shales, and again red and green slates with dark argillaceous shales, carrying the Normans Kill graptolitic fauna. Lentiles of limestone occur bedded in the shales, in which the Calciferous, Chazy, and Trenton faunas are found—sometimes one or two in the same lentile, as in Washington County, New York. On the east side of the Hudson Valley 5,000 feet of shales, slates, sandstones and limestones, of very irregular succession, may be referred to the Hudson terrane.

The evidence now at hand leads to the conclusion that in the valley of the Hudson, or the northern portion of the Appalachian trough, the sedimentation, from the Upper Cambrian to Lower Helderberg time, was unlike that of the region to the westward. It was greater in quantity and variety, and during Trenton time a graptolitic fauna was buried in it, such as is unknown elsewhere in New York and the southern Appalachians, although present in Arkansas and Nevada. All attempts to correlate the Hudson series with sections elsewhere must be more or less defective, except that the great mass is of Lower Silurian (Ordovician) age. The best region to study the Hudson series is from Fort Edward, above Albany, to the vicinity of Catskill.

In Dutchess County, opposite Kingston, the Lower Cambrian quartzite rests on the Algonkian gneisses, and the stratigraphic section is represented from this horizon to the Trenton and Lorraine. South of Poughkeepsie, on the east side of the river, the sedimentary beds are crowded out to the river by the pre-Cambrian rocks, and below Newburg

the crystalline schists of the Highlands occupy the western shore until the trap ridge of the Palisades is encountered. At **Weehawken** the characters of the trap are finely shown in the quarries.

The drift features, from **Niagara Falls** to **Schenectady**, include at first ground moraine with undulating surface, and afterward, between **Rochester** and **Syracuse**, a tract of drumlins of the more elongated type. At **Little Falls** the Mohawk River appears to have cut a postglacial channel, and fine river terraces occur above the gorge through which the river passes. Below the falls the river silt and gravels nearly fill the valley from side to side.

The most important Pleistocene deposit of the Hudson Valley is a great bed of laminated clay referred to the Champlain epoch and known locally as the Albany clay. It is the sedimentary record of a large estuary occupying the Hudson Valley after its abandonment by the ice, and it appears originally to have stretched from side to side of the valley, filling the river channel and masking the rugosity of the base-level plain. Near **Schenectady** its upper surface bears a heavy layer of sand. After its deposition the land rose temporarily to a height greater than the present, permitting the river to carve its channel to such depth that it has not since been refilled with alluvium. The so-called river is still an estuary for 150 miles (240 km.) from its mouth, transmitting ocean tides as far as Albany.

From the terminus of the West Shore Railway at **Weehawken** travelers are transferred to **New York City** by ferry.

EXCURSION TO THE CANYON OF THE COLORADO.

DENVER, COLORADO, TO FLAGSTAFF, ARIZONA.

ITINERARY.

Station.	Distance.		Elevation.		Station.	Distance.		Elevation.	
	Miles.	Kilometers.	Feet.	Meters.		Miles.	Kilometers.	Feet.	Meters.
Denver*	0	......	5,182	1,579	Azul	389	626	6,672	2,034
Colorado Springs†	73	117	5,978	1,822	Las Vegas	395	636	6,383	1,945
Fountain	86	138	5,552	1,692	Romero	400	644	6,288	1,917
Buttes	93	150	5,353	1,632	Sulzbacher	409	658	5,975	1,821
Pinon	104	167	5,022	1,531	Tecolote	411	661	5,846	1,782
Pueblo‡	117	188	4,653	1,418	Bernal	414	666	6,068	1,849
Baxter	123	198	4,602	1,403	San Miguel	425	685	6,021	1,835
Chico	129	208	4,532	1,381	Sands	430	693	6,388	1,947
Boone	136	219	4,460	1,359	Fulton	432	696	6,527	1,989
Nepesta	144	232	4,356	1,328	Rowe	441	710	....	....
Rocky Ford	169	272	4,162	1,269	Pecos	446	718	6,366	1,940
La Junta	180	290	4,046	1,233	Glorieta	451	726	7,417	2,261
Benton	189	304	4,263	1,299	Canoncito	455	732	6,855	2,089
Timpas	198	319	....	....	Lamy	460	740	6,460	1,969
Iron Springs	208	335	4,676	1,425	Ortiz	472	760	5,821	1,774
Delhi	217	349	5,042	1,536	Los Cerrillos	478	769	....	....
Thatcher	225	363	5,401	1,646	Wallace	491	790	5,248	1,600
Tyrone	235	378	5,520	1,682	Elota	498	801	5,125	1,562
Earl	244	393	5,673	1,729	Algodones	502	808	5,099	1,554
Hoehnes	253	407	5,706	1,739	Bernalillo	511	822	5,099	1,554
Trinidad	262	422	5,967	1,819	Alameda	520	837	4,981	1.518
Starkville	267	430	6,333	1,930	Albuquerque	528	850	4,935	1,504
Morley	272	438	6,748	2,057	Laguna	594	956	5,869	1,789
Wooton	277	446	....	....	McCartys	611	983	....	....
New Mexico line	277	446	....	....	Bluewater	635	1,022	....	....
Raton	285	459	6,622	2,018	Continental Divide	......	......	....	....
Dillon	288	463	6,456	1,968	Coolidge	664	1,068	6,977	2,127
Maxwell City	311	500	....	....	Wingate	674	1,084	6,714	2,046
Dover	319	513	5,819	1,774	Defiance	694	1,117	....	....
Springer	325	524	5,768	1,758	Manuelito	702	1,130	....	....
Wagon Mound	351	565	6,178	1,883	Carrizo	766	1,233	5,199	1,584
Tipton	361	581	6,365	1,940	Holbrook	781	1,257	5,069	1,545
Shoemaker	368	592	6,256	1,907	Winslow	813	1,308	4,824	1,470
Watrous	376	605	6,398	1,950	Canyon Diablo	839	1,350	5,399	1,646
Onava	385	620	6,730	2,051	Flagstaff	872	1,403	6,864	2,092

* Population, 106,713. † Population, 11,140. ‡ Population, 24,558.

[By S. F. Emmons.]

The route between **Denver** and **Colorado Springs** has already been described (p. 434).

From **Colorado Springs** nearly to **Trinidad** the road crosses open, unincidented plains of Middle Cretaceous shales, in which the only geological landmarks are occasional outcrops of the harder beds of the Niobrara limestones carrying abundant casts of *Inocerami*.

The road first runs south along the alluvial bottom of Fountain Creek to **Pueblo**, then bends eastward and follows the bottom lands of the Arkansas river to **La Junta**, from which point it takes a southwest course, leaving the river bottom and following the gently rolling plains and the beds of various streams which rise in the Sangre de Cristo range to the southwest. Over all these barren-looking plains large herds of cattle and sheep are grazed, and, wherever there is sufficient water for irrigation, the various cereals and many varieties of fruits are successfully cultivated.

Before reaching **Trinidad** the beautiful eruptive mountain group of the Spanish Peaks can be seen about 35 miles to the westward.[87]

They consist of two distinct peaks—an eastern (12,720 feet, 3,877 m.) and western (13,620 feet, 4,151 m.)—which rise out of a platform of Laramie Cretaceous and recently-discovered Eocene Tertiary beds (known as the Huerfano beds), about 10 miles east of the Sangre de Cristo mountains. They are of the laccolitic type, but not so regular or symmetrical as the Henry mountains. The laccolite, which spreads out in the softer shaly beds of the Colorado Cretaceous, is about 2,000 feet thick in its central portion, and sends out an intricate system of dikes through the overlying beds, which are so thoroughly metamorphosed that they were assumed by the first observers in this region to be of Carboniferous age.

The San Juan branch of the Denver and Rio Grande road crosses the Sangre de Cristo range into the San Luis park at Veta Pass just to the right of the Spanish Peaks.

At El Moro, to the right before reaching **Trininad**, are the coke ovens of the Denver and Rio Grande Railroad.

Trinidad owes its importance to the vicinity of most valuable beds of excellent coking coal, admirably situated for economical exploitation.

The thickness of Laramie measures, reckoning from the top of the sandstones to the Fort Pierre shales which outcrop at their base, is estimated to be about 1,800 feet. They contain 32 coal seams, which have an aggregate thickness of 105 feet, though the seams are by no means continuous throughout the field. The areal extent of the coal field is about a million acres.[88] The coal is either a slightly caking

or else a coking coal, differing thus from the coals of the Denver basin at the same horizon, which are non-coking and quite porous and hygroscopic. The Laramie sandstones lie in an approximately horizontal position, and are capped, to the east of the road, by overflows of basalt, the greater mass of which forms Fishers Peak (9,460 feet, 2,843 m.), which is about 3,300 feet above the town to the southwest. This is the culminating point of the Raton hills, a broad, flat-topped ridge which extends eastward from the base of the mountains and forms the divide between waters flowing into the Arkansas on the north, and those flowing southward through New Mexico and Texas directly into the Gulf of Mexico.

The difference between slightly caking and coking coal in this field bears an evident relation to the magnitude of the neighboring eruptive masses, the coking coal occurring in the portion underlying the Fishers Peak overflow. In many parts of the field the injection of lava along a coal seam has produced either a dense natural coke or an impure powdery graphite. The outcrop of natural coke near **Trinidad** is probably two miles long. In other parts of the field outcrops of coke have been traced 4 and 5 miles. In a few places limited quantities of semi-anthracite have been produced. The neighboring sandstones are altered to quartzites.

From **Trinidad** the road rises, in a valley bordered by bluffs of Laramie sandstones and shales, to **Starkville**, at the west base of Fishers Peak.

Between **Morley** and **Lansing** the boundary line between Colorado and New Mexico is crossed. The edges of the coulées of basalt, capping the mesa, can be distinguished on the east.

The road now descends rapidly to **Raton**, and passes out into the broad, open valley of the Canadian river, eroded out of Middle Cretaceous shales.

At **Maxwell** the hills to the east are capped by basalt. This is on the well-known Maxwell Grant, one of the grants of land made by the Spanish authorities before New Mexico was ceded to the United States. At the time these grants were made land had little value, and the boundaries of the grants were very loosely defined by natural features, such as streams and watersheds, whose names have since been changed. The treaty of cession provided that the U. S. Government should confirm titles to lands thus granted. This particular grant, as surveyed for the persons who purchased it from the original grantees, covered in the neighborhood of a million acres. It was sold by them to Dutch capitalists. Since the sale there has been long litigation, based upon an asserted fraud in making the surveys of the boundaries. As these surveys had been accepted by the U. S. Land Office, the title of the present holders was finally confirmed.

Cimarron Creek, a tributary of the Canadian, which drains an interior monoclinal valley of the southern portion of the Sangre de Cristo range, is crossed at **Springer** station.

At **Wagon Mound** the road traverses a gap in basalt between Ocate mesa on the west and the Canadian hills on the east, both of which are capped by basalt. South of the Ocate mesa and west of the road are the Turkey mountains, which are formed of Carboniferous strata surrounded by Dakota sandstones, which dip gently away in all directions.

At **Tipton** the road has passed on to the Dakota sandstones, which underlie the shales. Directly west of this station, on the southern point of the Turkey mountains, is an extinct basaltic volcano with extremely perfect crater, whose rim is broken only by a narrow gap on the south side. According to Prof J. J. Stevenson[89] a coulée from this crater flowed south down Cherry Creek to the canyon of the Mora river, and then east along the bottom of this canyon to its junction with Canadian river, 30 miles to the eastward. In the upper part of the canyon only fragments of the coulée remain, but below it is continuous for nearly 20 miles. This flow occurred at a time when the Mora canyon, at its lower end, had been eroded to a depth of 860 feet (262 m.) below the top of its present walls. The basalt coulée then filled the bottom of this chasm to a depth of 400 feet; since which time the stream has eroded a new channel, partly in the basalt, and partly in the sandstone on one side of it. This latter channel, at the mouth of the canyon, is 230 (70 m.) feet below the base of the lava and 1,090 feet (322 m.) below the plain.

From **Shoemaker** to **Watrous** the road follows the valley of Mora river in Dakota sandstones. It then bends southwestward across a plain of Middle Cretaceous shales to **Las Vegas**, whose fine thermal springs lie a few miles west of the main line, at the foot of the steeper slope of the mountains. Here the railroad company has built a bathing establishment and a handsome hotel, which has several times been burned down.

From **Las Vegas** the road runs southward into Dakota sandstones, resting against the upturned Carboniferous beds which form the southeastern extremity of the Sangre de Cristo range.

At **Bernal** it turns westward, along the northern base of a mesa of Dakota sandstones, and passes into the valley of the Pecos river. It then bends northwestward and follows along the south side of the valley of the Pecos to near its source at **Glorieta**. It then bends southwestward, cutting through a projecting tongue of the Dakota mesa at **Canoncito**, and passes into the valley of Gallisteo creek.

At **Manzanares** it touches the southern point of the southwest extremity of the Sangre de Cristo range, which is formed of Archean with an encircling fringe of Carboniferous beds.

From **Lamy** a branch runs north across Tertiary beds (Santa Fe marls) 40 miles (65 km.), to Santa Fe, one of the oldest settlements in the United States. Like many other Spanish towns of the Southwest, it occupies the site of an Indian pueblo.

The road now passes into the Laramie coal-bearing rocks, in which some mines have been opened not far from **Ortiz**. The beds are, however, much broken by eruptive rocks, and the coal in some cases has been changed to anthracite. In the valley to the south, around the Placer mountains, is a considerable accumulation of gold-bearing gravels which might be profitably worked if it were not for the absence of water.

To the north of **Los Cerrillos**, in the hills of the same name, turquoise is found in rhyolite. The mines from which this mineral is obtained are supposed to have been worked by the Aztecs before the advent of the Spaniards.

Beyond **Wallace** the road enters the valley of the Rio Grande del Norte. This stream takes its rise in the various mountains which surround the great interior valley of San Luis Park. After leaving this well-watered and fertile valley it passes through narrows formed by coulées of basalt into the arid regions of New Mexico. To one coming from the east the portion of the valley followed by the railroad has a general aspect suggestive of that of the Nile. The river flows in a broad alluvial bottom, bounded by low bluffs at considerable distances back from the river. In the early summer, when the snows melt in the mountains, its waters spread out over the bottoms and leave a thin deposit of fine alluvial soil, which soon becomes brilliantly green with growing crops and fruits. As the river falls, the heat of summer gradually turns this verdure to a somber yellow or drab, except in a few favored spots. The old-world aspect of the valley is heightened by the quaint old Spanish towns, largely built of adobe or sun-dried bricks, and still more by the villages of the Pueblo Indians, built of stone, but plastered over the surface with mud.

[By G. K. Gilbert.]

East of **Albuquerque** stand the Zandia mountains[90] overlooking the Rio Grande with a bold mural front, even and straight, and little gashed by canyons. From the water to the crest the rise is 7,000 feet (2,100 m.). Except the crest the whole front is Archean, but from end to end there is a cornice of Carboniferous limestone a few hundred feet thick, that by its continuity shows the whole was raised in a single unshattered mass. The eastern face is of easier slope, but is less regular. The limestone band, that forms the persistent and almost level line of crest, is the edge of an eastward-dipping bed that is succeeded in that

direction by superior Carboniferous and Mesozoic strata, all dipping from the mountain. But going westward from the Archean belt the unaltered rocks are not found in the same order. The tough Carboniferous limestone that holds its own so valiantly on the summit does not appear at the west, as it should if the structure of the mountain were anticlinal; but the first strata seen, after passing the valley gravels, which bury the base of the Archean wall, are of Cretaceous age, and they dip toward, rather than from, the ridge. The mountain is a great but simple monoclinal mass, bounded on the west by a profound fault, along the line of which is the river valley. The difference of level between the Carboniferous strata on the crest of the mountain and the dissevered fraction of the same strata, buried far below the Cretaceous rocks in the valley, is not less than 11,000 feet (3,300 m.), and something greater than this must have been the throw of the fault that separated them.

Thence, westward to **Flagstaff** and northward to the Grand canyon of the Colorado, the route lies exclusively within the Plateau region. The rocks are Cretaceous, Jura-Trias, Carboniferous, and volcanic. The Cretaceous system includes alternations of yellow sandstones with gray argillaceous shales, and there are occasional beds of coal. The maximum thickness is about 4,000 feet (1,200 m). The Jura-Trias is composed of sandstones with sandy shales and marls, and is everywhere characterized by brilliant colors. In the upper part of the system lenses of gypsum occur, and further west beds of salt are associated with them. At the west, calcareous beds have been found in the upper part, with marine shells, called Jurassic. Farther east, beds near the summit of the series have yielded plants referred to the Trias, and bones referred to the Jura. About the Zuni uplift[91] the most conspicuous member of the system is the Wingate sandstone, a massive bed nearly 500 feet (150 m.) thick occurring near the middle of the system, which has here a total depth of about 3,500 feet (1,000 m.). Farther west another massive bed appears near the upper limit, and acquires topographic prominence. The Carboniferous system is characterized by two great beds of limestone, which weather but slowly and are thus rendered prominent in the topography. The lower appears in the Grand canyon of the Colorado; the upper, known as the Aubrey limestone, is seen in the Zuñi mountains, and constitutes a large portion of the plateau traversed between **Flagstaff** and the Grand canyon. Above this are a few hundred feet of bright-colored shales and sandstones, resembling the Jura-Trias rocks, but classed with the Paleozoic by reason of fossils of Permian type discovered in southern Utah. The same Permian facies characterizes fossils of the upper layer of the Aubrey limestone.

Associated with these are volcanic rocks with many modes of occurrence. Basic lavas, chiefly andesitic, rest upon the plateau in great

cones built in Tertiary time, and left by the progressive degradation of the region upon pedestals of less resistant rock. Next in importance are lava flows, partly andesitic, but largely basaltic, and of such antiquity that the country has been eroded about them, leaving them as caps of small plateaus or mesas. In some cases, where the outpoured lava has been removed by erosion, the congealed lava of the conduit remains as a volcanic neck. Of more modern date, and often of extreme recency, although not historical, are basaltic cinder cones and basaltic coulées, which diversify the plateaus and course through the valleys.

Normally the strata are approximately level and interest centers in the variations from this attitude. The Zuni mountains were produced by a moderate uparching, the axis of which trends northwest and southeast. On the northeast side the dips are gentle; on the southwest steep. From the northwestern end of the uplift, a monoclinal fold—the Nutria fold [91]—continues for several miles, and then gradually fades out. Where a monoclinal fold is normally developed it is the equivalent of a fault, except that strata are flexed instead of fractured; in this case flexure and fracture are combined (Fig. 29). Farther westward another monocline, the Defiance fold, is seen, as well as minor flexures, and near the Grand canyon yet others.

The San Mateo Plateau is occupied by an immense composite sheet of lava 700 square miles (1,800 sq. km.) in area. By the degradation of the surrounding Cretaceous rocks it has received a relative altitude of more than 1,000 feet. Upon it stand numerous cinder cones and the great andesitic mass of Mount Taylor, and around about it a multitude of volcanic necks testify to its greater original extent. Mount San Francisco, likewise a great cone of andesite, was built upon Jura-Trias rocks, but these have been worn from the surrounding plain, together with all other strata down to the Aubrey limestone, and the talus of andesite almost completely conceals the sedimentary pedestal, so that the peak seems to spring 5,000 feet (1,500 m.) into the air from a plain of Aubrey limestone. All about it are more recent basaltic cinder cones and lavas.

Where the train enters the Plateau region, soon after crossing the Rio Grande, it follows a valley cut through the Cretaceous and into the Jura-Trias. Near **Laguna** it rises to the Cretaceous, but before that point is reached a fresh black lava stream appears in the valley, and this is kept in sight for many miles. Thence to **McCartys** the visible sedimentary rock is all Cretaceous. Northward at a short distance appears the San Mateo plateau, with Mount Taylor on its back, and in the face of the plateau are to be seen folds of Cretaceous strata formed previous to the volcanic eruption. Nearer by are several buttes, constituted by volcanic necks, and just beyond **Cubero** station is a dome-like lava cone. At **McCartys** another fresh lava stream is encountered in the valley, and this remains in sight until **Bluewater** is passed. A few miles beyond **McCartys** the train passes from Cretaceous to Jura-Trias rocks, but the character-

istic features of the system do not appear until the lava is left behind. From near **Bluewater** to Mineral spring the train follows a monoclinal valley belonging to the northeastern flank of the Zuñi uplift. Beneath the track is the lower division of the Jura-Trias. At the right are a series of picturesque vermilion and orange bluffs and towers marking the outcrop of the Wingate sandstone. Farther back a second cliff line marks the outcrop of the basal sandstone of the Cretaceous. On the left rises the Zuñi range, exhibiting over large areas the upper surface of the Aubrey limestone, denuded of all superior strata and embodying on its surface the details of mountain structure. With favorable light, a system of minor faults and monoclinal flexures can be confidently traced from a distance.

The slopes of the valley are gentle, but its drainage is curiously divided, a part going to the Atlantic and another part to the Pacific. Quite unconscious that his train is surmounting a summit, the traveler here crosses the **Continental divide.**

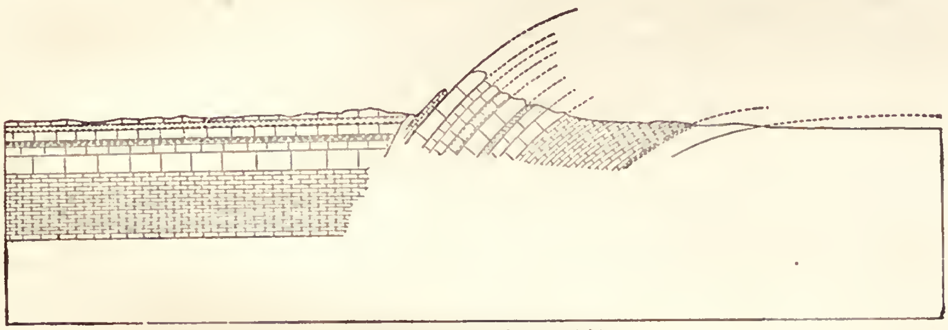


FIG. 29.—The Nutria fold.

At Mineral spring the Nutria fold is crossed. To the northward the strata can be seen to arch over and then suddenly descend. To the southward the fold is marked by a line of rocky crags. Thence to **Manuelito** the way lies among mesas of Cretaceous rock. A little west of **Manuelito** the Defiance fold is encountered—a monoclinal similar to that of Mineral spring, but of opposite throw. The Jura-Trias is again brought to the surface, and upon it the train continues to the crossing of the Little Colorado at **Winslow.** The beds here seen belong chiefly to the lower portion of the system, including perhaps also the upper of the strata referred to the Permian. Their varied hues in this desolate region have given name to the Painted desert, but near the Little Colorado they are partly concealed by alluvium.

From **Winslow** to **Flagstaff** the prevailing rock is Aubrey limestone, which rises westward from beneath the Jura-Trias. Its surface is disturbed by minor faults and folds, and diversified by basaltic mesa and cinder cones; and about San Francisco Mountain it is clothed by a noble forest of yellow pine (*Pinus ponderosa*).

Where the drainage lines cross low anticlines of the limestone they are sharply incised, and two such trenches are crossed by the railway.

The greater of these, Canyon Diablo, has a depth of 250 feet (75 m.) and has given name to the railway station just east of it.

At **Flagstaff** the mode of travel changes; the party is conveyed by wagons and saddle horses, takes its meals out of doors, and sleeps in tents.*

FLAGSTAFF TO THE GRAND CANYON.*

By G. K. Gilbert.

Flagstaff stands at the southern base of San Francisco Mountain. The road to the brink of the Grand canyon curves eastward about the mountain and then takes a northerly course. In the vicinity of the mountain are a great number of basaltic cinder cones from 500 to 1,500 feet (150 to 450 m.) in height, and most of these are so newly formed that their craters are well preserved. A few are not yet clothed with vegetation, and one, Sunset peak, is associated with a black lava field equally barren. The sides of this cone are of black lapilli, but its crest is tipped with red in a way to suggest that it catches the last rays of the setting sun. In the crest of another cone are artificial caves dug by Indians to serve as dwellings, but long abandoned.

The general altitude of the plateau is 7,000 feet (2,100 m.), and it is beautified by forests of pine, which give peculiar delight to eyes wearied with treeless plains and mesas, but water is nevertheless scanty. There are no streams, and springs are rare. Hull spring, the first one seen by the party, is a day's journey from Flagstaff and determines a point of encampment. The degradation of the country has here progressed several hundred feet since the spreading of a great field of basaltic lava, and the beds of resistant basalt cap a mesa facing toward the north. Beneath are soft shales of Permian age, and the water stored in the crevices of the basalt escapes slowly at the plane of contact.

The sloping Permian outcrop is sheathed by fragments of the basalt, which breaks away in huge blocks as it is sapped. One of these blocks, separated from the main cliff by a chasm a hundred yards across, was chosen as the site of an Indian village and covered with stone houses. The ruined walls remain, with fragments of pottery, and chips of flint and obsidian.

From Hull spring northward the road descends below the zone of trees and for 20 miles (30 km.) traverses a prairie floored by Aubrey limestone. Continuing on the same terrane, it then rises again into the zone of pine forest, and there remains till the brink of the canyon is reached. This timbered upland is the Cosnino plateau, the companion and counterpart of the Kaibab plateau north of the river. Indeed the two are parts of one uplift divided by the corrading river.

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*The prophecy of "tents" was not verified; the party bivouacked, and was so unfortunate as to encounter storms of rain, snow, and wind.

The Aubrey limestone withstands erosion so much better than the Shinarump (Permian) shales and sands above it, that its surface has been denuded over a vast area and constitutes the floor of the country. Each great orogenic block stands as a plateau, each fault is marked by a cliff, each rock flexure is revealed in a topographic profile. Through this grand tectonic model runs the river's trench, revealing its anatomy in either wall.

The brink of the chasm is reached at a point nearly opposite Point Sublime, and the view does not differ in character from that sketched by Holmes.[93, 94] The canyon is here broad and its walls are elaborately sculptured in sinuate terraces and cliffs, with buttresses, alcoves, pyramids, and spires innumerable. The Aubrey limestone and a firm sandstone beneath it, both pale in tint, constitute the first cliff, and a broad sloping terrace below it reveals a series of bright red shales and sandstones likewise of the Aubrey group. The foundation of this terrace and the material of the next cliff is a massive gray limestone, named the Red Wall because generally stained by pigment washed from above. The cliff is 1,000 feet (300 m.) high, and can be scaled only here and there in a deep recess. The next terrace is due to sandy shales of dingy hues, green, gray, and brown—the Tonto shales; and the Tonto sandstone forms a chocolate-colored cliff beneath.

The Aubrey beds and the Red Wall limestone carry Carboniferous fossils; there are Cambrian fossils in the Tonto shales and Tonto sandstones. Devonian and Silurian claim a narrow zone at the base of the Red Wall. Beneath the Tonto sandstone is a profound unconformity; it rests partly on Archean schists and granite, partly on basset edges of two great systems of Algonkian strata, comprising all ordinary types of clastic rocks, but yielding only tantalizing traces of contemporary organisms. These systems are themselves separated by an unconformity, and a still greater break divides the lower from the Archean.

PUEBLOS.

To the ethnologist this whole region is of special interest by reason of the opportunities afforded to study the institutions, arts, and architecture of Pueblo Indians. From the train may be seen the villages of **Isleta** and **Laguna**, besides a number of outlying farms and hamlets belonging to **Laguna**, and the whole region abounds with ruins and other vestiges of more extended occupation. Through an immense area, comprising the half of Colorado and Utah and the greater part of Arizona and New Mexico, there is scarcely an acre on which shards of Pueblo pottery may not be found. Though the houses are of stone, the mortar employed has no lithifying principle and yields to the storms, so that the walls of abandoned houses are apt to fall, but a multitude of structures built in shallow caves on the faces of cliffs have been preserved, enabling the student to assure himself of the identity of the culture represented by the ruins with that of the modern villages. A group of cliff dwellings is readily accessible from **Flagstaff**.

NOTES AND SKETCHES BY VISITING GEOLOGISTS.

NOTE ON WALNUT CANYON AND ITS CLIFF DWELLINGS.

By Prof. T. McK. Hughes.

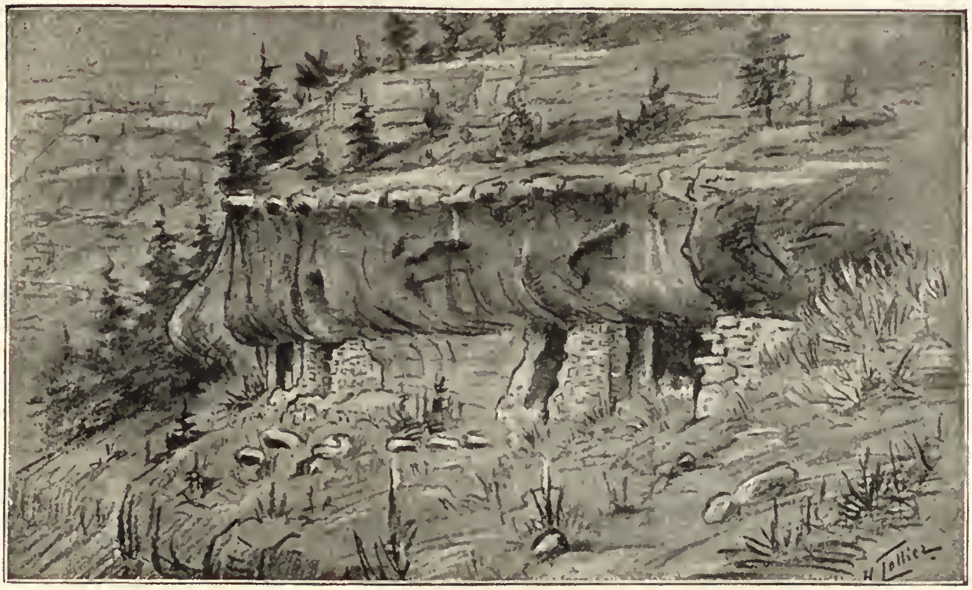

Fig. 30.—Cliff dwellings in Walnut canyon.

Walnut canyon, 8 miles (12 km.) southeast from Flagstaff, Ariz., is a dry canyon in summer, but after the rains the channel is a roaring torrent. It is cut to a depth of 250 feet (85 m.) in the Aubrey or Upper Carboniferous rocks, which yielded to our party two species of *Productus* and some mytiloid lamellibranchs. The lower half (Fig. 31–2) consists of false-bedded sandstones of very uniform character, the breadth of the bands picked out by the principal divisional planes, whether of bedding or cross-bedding, being approximately the same from top to bottom, and the flat clean-cut wall showing no evidence of alternations of harder and softer beds. Not so the upper half of the side of the gorge, which consists of irregular beds of limestone, some of which protrude in ledges of varying thickness, while others have flaked off under the influence of the weather and receded into continuous rock-shelters, like those in the mountain limestone along the vale of Clwyd in North

Wales or the *abris* along the Vézère in Mesozoic rocks. As in the cliff of Dordogne, so in the Walnut canyon, these shelters have been occupied by people whom the necessities of primeval life or the exigencies of war drove to easily defended fastnesses in the rocks. They do not imply that the races who availed themselves of these strongholds were in a more rude stage than those who lived in huts upon the plateau. In the Middle Ages the Rock of Tayac was long held by the English, and so the remains left by the Indian tribe which occupied these cliff dwellings in the Walnut canyon did not lead us to infer that it was in an early stage of civilization. The fragments of pottery showed much artistic taste and skill. The stone arrowheads were highly finished and of the same type as those used by the Indians of historic time. The walls of the dwellings were of stone cemented by mortar, in which were pieces of pottery, showing that the building was still going on after the tribes had lived there for some time and scattered household rubbish about. Cobs of Indian corn told of cultivation, while their state of preservation confirmed the impression, derived from the mortar and other remains, that there was no ground for assigning the occupation of the cliff to any remote antiquity.

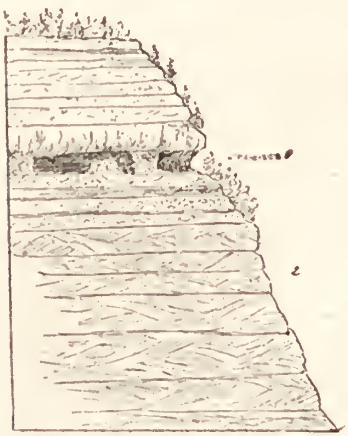

Fig. 30.—Section in Walnut canyon.

SECTION IN CONGRESS CANYON OPPOSITE POINT SUBLIME.

By Dr. Fritz Frech.

The succession of strata exposed in the Grand Canyon of the Colorado has already been several times described (95.96.97).

But all the sections hitherto published differ somewhat in regard to the petrographical character, the relative thickness and the disturbances of the strata, and as the section shown in Congress canyon has not been investigated before by any geologist, it may well be described at some length. The section is interesting not alone for the opportunity it affords to make a diagnosis of the petrographical character of the strata. There are probably few places on the earth where the geological phenomena of folding, faulting, uplifting, as well as numerous transgressions, may be so easily taken in at a single glance.

As the geologist passes upward from the bottom of the canyon to Hance's cabin he crosses the terranes of the following principal geolog-

ical divisions: Archean, Algonkian, Cambrian, and Carboniferous. The more important divisions of these groups are marked by the Roman numerals I to VII, in ascending order, in Fig. 32.

I. *Archean.* Gneiss with intrusive dikes of granite, pegmatite, and later diabase.

II. *Algonkian.* Grand Canyon series,* lying unconformably on the gneiss. Coarse red sandstones, shales, and conglomerates, with a sheet of diabase in the lower part (intrusive or surface flow?). Its total thickness, as observed at other points, is over 13,000 feet (4,000 m.); in this section only 300 to 400 metres are exposed.

III and IV. *Cambrian,* (about 1,000 feet (305 m.) thick) lying unconformably on the upturned edges of the Algonkian beds. The faults which traverse the latter beds terminate at the base of the Cambrian.

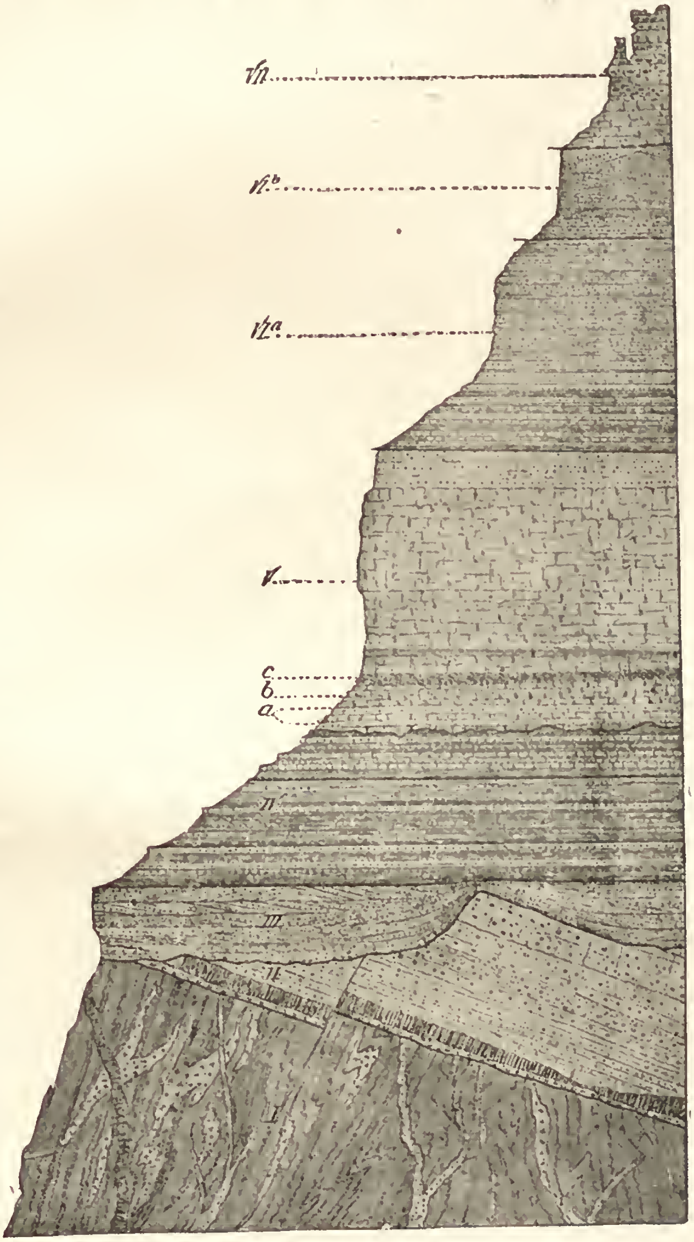

Fig. 32.—Section in Congress canyon.

*The Grand Canyon series is fully developed only in the main canyon and thins out in the smaller valley through which the trail from Hance's cabin descends. The Cambrian sandstone rests directly on the gneiss in the picturesque niche or panel[94] called St. Gabriel's Cathedral (25 m. high), where the geologists camped the first night.

The Cambrian is subdivided into—

III. *Lower Tonto*, (about 300 feet) massive red sandstones with Scolithus at the top.

IV. *Upper Tonto*, (about 475 feet) greenish shales and shaly sandstones with impure limestones in the upper part.

The Devonian, which has been observed by Walcott[95] on the other side of the Grand canyon, between Marble canyon and Kaibab plateau, is altogether wanting at this point. The unconformity of erosion at the base of the Red Wall limestone, observed by the same geologist, is also very obscure here. There seems to be a gradual passage from the arenaceous sediments of the Tonto to the Carboniferous limestones above, but the fact that a sandstone bed is intercalated at the base of the Carboniferous limestones is consistent with Walcott's observations.

V. *Lower Carboniferous*, ca. 1,000 feet. Red Wall limestone.

(*a*) At the base: alternating sandstone and limestone.

(*b*) Red and white stratified (thin-bedded?) limestone, in part crinoidal limestone with casts of *Spirifer striatus*.

(*c*) Bed of bluish brecciated limestone.

Above these comes the cliff of the Red Wall; it consists of a massive or obscurely bedded pure white limestone, which is superficially colored by waters seeping through the red beds of the Aubrey group.

VI and VII. *Upper Carboniferous* or Aubrey group.

VI (*a*). Lower Aubrey sandstone and shale, ca. 1,000 feet. The upper and lower parts are formed by thin-bedded sandstones and shales; in the middle there is a well defined cliff of massive sandstones.

VI (*b*). White Aubrey sandstone, ca. 400 feet, cross-bedded and forming a steep cliff distinctly visible from a long distance as a white band in the midst of the red rocks.

VII. Aubrey limestone and dolomite, ca. 500 feet (800 feet on the other side of the canyon). In the lower part is found a pure limestone which rests directly on the sandstone without any transition. The upper part consists of cherty limestones which contain a large *Allorisma* and some ill-preserved gasteropoda (*Euomphalus* and *Pleurotomaria*). In Coconino or Walnut canyon, near Flagstaff, the following Brachiopoda were found in the faint pink-colored dolomite in which are the famous cliff dwellings. (See p. 475.)

Productus Ivesii, Newberry, very common.

Productus aff., *scabriculus*, rare.

Spirifer (*Martinia*) *lineata*, Marsh, rare.

The specimens of *P. Ivesii* are very clearly related to the Upper Car-

boniferous form of *P. semireticulatus*, which Dr. E. Schellwien* has named var. *bathycolpos;* but in *P. Ivesii* the ribs of the shell and the spines are more strongly developed and the medial septum in the smaller valve is divided. *P. Ivesii* should be considered a variety of *P. semireticulatus* and not a distinct species.

The principal terraces are developed at the horizons of the Upper Tonto (IV), and at the base and top of the Lower Aubrey sandstone (VI *a*). They are indicated by the reduced slope of the cliff in the accompanying section (Fig. 32). The actual slope of these terraces could not be given for want of space.

The principal cliffs are formed by the Archean, the Grand Canyon and Lower Tonto series and the Red Wall. The picturesque carved (or incised) forms of the latter have a remarkable resemblance to the Dolomite cliffs of the Upper Trias in southern Tyrol.

The following table gives the results of a more detailed examination of the Tonto series (III and IV):

			Feet.
III.	1.	Coarse, red, cross-bedded sandstones, with pebbles of quartz at the base and *Scolithus* at the top.......ca..	260
	2.	White sandstone, spotted black	30
IV.	3.	Thin-bedded, brown, quartzitic sandstones and shales.......	14
	4.	Yellow and chocolate-colored, sandy shales, alternating with cross-bedded sandstones and conglomerates	45
	5.	Well-defined bed of brown sandstone with glauconite(?), containing *Obollela*.......	4
	6.	Greenish or snuff-colored, shaly sandstone with worm tracks (*Cruziana*), ripple-marks and glauconite (?) (*Obollela polita* Hall? *Lingula monticula* Walcott?).......	65
	7.	Same rocks as in 5 and 6. Large ripple-marks in the lower part, and in the upper part a glauconite layer 5 to 15 cm. thick. *Obollela* sp.?..	32
	8.	Snuff-colored sandstone, forming a well-defined cliff 8 feet high. In the upper part some calcareous shale.......	85
	9.	Greenish or snuff-colored shales with small ripple-marks, forming a gentle slope.......	85
	10.	Same beds as in 8. In the upper, a bed of limestone forming a small cliff.......	44
	11.	Greenish shales, with small cliff in the midst formed by a greenish sandstone.......	85

The section shown in Congress canyon is in many respects incomplete. The following table, made by C. D. Walcott [96] at the Kaibab Plateau on the north side of the Grand canyon, gives the complete section (Roman numerals denote corresponding beds observed in Congress canyon):

	Feet.
Tertiary	815
Cretaceous.......	3,095

*To whom I am indebted for the determination of the two Productus. Compare the figures of *P. semireticulatus* White, G. and G. Surveys W. of 100th meridian, Vol. IV. p. 111, Pl. VIII, fig. 1, and *Productus Sp.?* Meek. U. S. G. Explor. 40th Par. Vol. IV p. 67, Pl. VII, fig. 6.

CONGRESS CANYON BELOW HANCE'S CABIN.

GRAND CANYON ABOVE THE MOUTH OF CONGRESS CANYON.

Jurassic (identified)			960
Jura-Trias			3,430
Carboniferous	Permian	854	4,106
	VII. Upper Aubrey limestone	805	
	VI. Lower Aubrey limestone	1,485	
	V. Red Wall limestone	962	
Devonian	Temple Butte limestone		94
Cambrian	IV. Tonto (calcareous and arenaceous shale)		1,050
	III. Tonto (sandstone)		
Algonkian	Chuar (shales and limestones)	5,120	12,950
	II. Grand Canyon (sandstones with lava flows in upper part)	6,830	
	Vishnu (bedded quartzites and schists)	1,000	
			26,500

GENERAL CONCLUSIONS.

The interest afforded by the Grand canyon section is not restricted to the mere petrographical and stratigraphical diagnosis of its beds. It would be difficult to find another locality where the geological changes induced by faulting, folding, and volcanic eruptions can be so easily observed at a single glance. As Capt. Dutton remarks: [94] "Probably there is no instance to be found in the world where an unconformity is revealed upon such a magnificent scale, and certainly not amid such impressive surroundings." If we attempt to read the pages of the gigantic manual of geology, which is revealed to us from the brink of the great chasm, we may decipher the following episodes in its ancient history:

1. Energetic folding of the gneiss, and simultaneous or subsequent intrusion of pegmatite dikes, which have also been folded.

2. Complete erosion and planing down of the pre-Algonkian mountains; deposition of 13,000 feet (4,000 m.) of Algonkian sandstones and shales.

3. Eruption of diabases [the diabase dikes which cross the pegmatites lie conformably between the Algonkian sandstones (whether surface flows or intrusive sheets?) but do not penetrate the younger rocks].

4. Upheaval and faulting of the Algonkian sediments and inclosed eruptive beds.

5. Transgression of the Upper Cambrian (Tonto) sandstones; incomplete erosion and planing off of the Algonkian land surface. [The Algonkian beds are partially or totally wanting between the gneiss and the Tonto series; in other words, the sediments thin out over the ancient reefs of the Cambrian sea.]

6. The Silurian is wanting, and at the top of the irregularly distributed Devonian there is an unconformity by erosion (without discordance of stratification). These facts may be explained in either of three ways: (1) The Canyon area became dry land before and after Devonian time; (2) or, after deposition of the Silurian strata, they

were subsequently removed by erosion; (3) or, no sedimentation whatever took place in the Silurian sea. In either case the changes observed were effected without any dynamic movement in the earth's crust. On the other hand, the unconformity between the Devonian and the Carboniferous is evidently due to some change in the sea level.

7. With the earlier Carboniferous begins a period of regular marine sedimentation, which went on uninterruptedly until the close of Permian time. Between Permian and Trias (in the Triassic, Shinarump, conglomerate), and again in Trias and Jura "we find instances of these peculiar unconformities by erosion without any unconformity of dip in the beds." [94]

In early Tertiary time a period of disturbance (folding and faulting) again set in in the Grand Canyon region, where no such changes had taken place since the Algonkian epoch. A typical instance of a flexure in the massive Red Wall limestone was observed in descending through the upper part of Congress canyon. The same phenomenon has been observed by Walcott, who pointed out the interesting fact that the pre-Cambrian and Tertiary movements took place on the same line of displacements. The upturning of the strata on the western side of the fault was effected during pre-Cambrian time; that on the eastern side during Tertiary time.[97]

It was at this time, probably, that the period of volcanic activity commenced, during which the San Francisco mountains were formed. After the formation of these andesitic mountains, basaltic eruptions took place, in which Dutton distinguishes an earlier and a later period. During the earlier, the plateau surface, now formed by the Aubrey limestone, was covered with Permian shales and clays. The basaltic flows of this time protected these Permian beds from subaerial erosion. Red Butte, which was passed during the second day's journey to the canyon, and consists of Permian capped by basalt, is a characteristic instance of such protection.

The cinder cones, lava flows, and ash beds near Flagstaff, passed during the first day's journey, belong to the very latest eruption and may be of very recent origin.

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